The Hong Kong Polytechnic University

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QUALITY FUNCTION DEPLOYMENT OPTIMIZATION WITH KANO'S MODEL

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

In today's highly competitive market, customer demand is a critical factor in the product design process that faces companies across all industrial sectors. The ability to deliver product designs that meet customer needs while making the designs manufacturable at a competitive cost becomes a major advantage for companies to compete in the market. Thus, companies have adopted a number of methods and tools to effectively capture customer needs and hopefully incorporate these requirements into product design to meet customer needs and achieve higher customer satisfaction.

Quality Function Deployment (QFD) is a well-known methodology for customer-oriented product design and development. However, traditional QFD analysis has confronted a major challenge in capturing and understanding customer needs accurately. Kano's model, which studies the nature of customer needs, provides a new way for QFD users to develop a better understanding of customer needs. This thesis presents a novel approach to integrating Kano's model into QFD for optimizing customer-oriented product design. It first applies the traditional Kano's model to collect and analyze primary customer data, then quantifies Kano's model by identifying relationship functions between customer needs and customer satisfaction, finally integrates both qualitative and quantitative results from Kano's model into QFD to formulate a mixed integer nonlinear programming model to optimize product design with the objective of maximizing customer satisfaction under cost and technical constraints. A case study concerning the notebook computer design is conducted to illustrate the application of the proposed approach.

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CHAPTER 1

INTRODUCTION

Quality in products and services has become a primary concern for companies who compete in today's highly competitive market. This is because intense global competition and increasingly demanding customers have made companies face greater challenges and difficulties in their businesses than ever before. Companies can no longer rely solely on high-volume and low-cost production to maintain growth or even survive in the market. Instead, they have directed their efforts towards pursuing high quality to remain competitive in the market.

Despite the fact that companies may have different definitions or standards of quality to be achieved, there is a general consensus that high quality does not simply indicate that the product is defect-free, while it focuses on various aspects of the product development process, for example, fitness for use, customer focus and conformance to engineering requirements. Among them, the most critical criterion for achieving high quality is to meet customer needs. Thus, how to accurately capture customer needs and incorporate them into product design and development to achieve high customer satisfaction and maintain customer loyalty arouses interest of both researchers and practitioners.

1.1 QUALITY MANAGEMENT

Meeting customer needs is increasingly regarded as a focal point of quality management. ISO 9001: 2000 clearly defines that the central purpose of a quality management system is to ensure that the organization provides goods or services that satisfy customers and maintain their loyalty. In order to achieve this objective, various methods and tools are accordingly developed to help companies work for a better understanding of customer needs and hopefully translate these customer needs into valuable technical information to direct the process of product design and development. Among them, Quality Function Deployment and Kano's model are two widely-used methodologies to address the issue of customer focus in product design and development.

1.1.1 Quality Function Deployment

Quality Function Deployment (QFD), which was first developed by Professor Yoji Akao and Professor Shigeru Mizuno in the late 1960s, is a widely-adopted methodology for customer-oriented product design and development. It is a systematic approach to translate specific customer needs into product requirements for design, development, implementation, and delivery of a product [Aka90]. In today's ever-changing socio-economic and technological environment, where the growing distance between producers and users is a concern, QFD becomes an important tool to link customer needs with design, development, engineering, manufacturing, and service functions in companies.

The House of Quality (HOQ) is the most recognized and commonly used matrix in the QFD methodology. It is a structured and systematic way to transform customers' needs for a product (WHATs) into prioritized engineering characteristics (HOWs) that can be subsequently translated into component characteristics, process plans and production requirements. According to Hauser and Clasusing [Hau98], it is "a kind of conceptual map that provides the means for inter-functional planning and communication." A typical HOQ comprises six main parts including customer requirements, technical requirements, a planning matrix, an interrelationship matrix, a technical correlation matrix, and a technical matrix as shown in Figure 1.1.

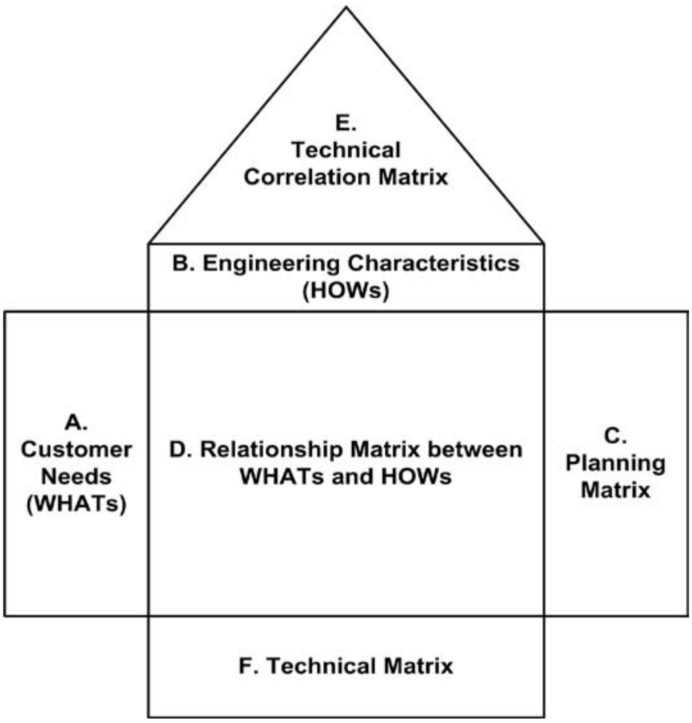

Figure 1.1 House of Quality (HOQ): brief description [Cha02]

While Figure 1.1 visualizes the structure of the HOQ, Table 1.1 gives a more detailed description of the contents in different parts of the HOQ.

Main Parts in the HOQ	Contents
Part A Left-hand side of the wall	**Customer requirements (CRs)** It identifies a list of customer needs, often referred to as the voice of the customer (VOC). The fulfilment of customer needs depends on the existence or performance of certain product features. These product features are referred as customer requirements in this context.
Part B Ceiling of the house	**Engineering characteristics (ECs)** ECs are also called technical measures or design characteristics. These ECs are methods, tools or measures that are adopted to realize the CRs for a product.
Part C Right-hand side of the wall	**Planning matrix** It lists the corresponding customer perception items observed through market survey such as competitive benchmarking, importance rating and selling point.
Part D Living room of the house	**Relationships between CRs and ECs** It illustrates the QFD team's perceptions of interrelationships between CRs and ECs. An appropriate measurement scale is applied, which is illustrated by symbols or figures.
Part E Roof of the house	**Correlations among ECs** The correlation matrix identify where technical requirements support or impede each other in product design. Trade-offs are made between similar and/or conflicting ECs through the correlations here.
Part F Foundation of the house	**Technical matrix** It prioritizes ECs and also determines the factors including technical benchmarking, target values and technical constraints.

Table 1.1 HOQ's contents [Xie03]

1.1.2 Kano's Model

Kano's model, proposed by the Japanese professor Noriaki Kano and his colleagues in 1980s, is a useful tool to capture customer needs and understand their impact on customer satisfaction. It categorizes different CRs based on how well they are able to achieve customer satisfaction [Kan84].

In the past, the relationships between CR fulfillment and customer satisfaction are always viewed in one-dimensional terms, that is, the higher the level of fulfillment in CRs, the greater customer satisfaction would be. However, the contributions to customer satisfaction by different CRs vary. Fulfilling customer expectations to a greater extent does not necessarily guarantee a higher level of customer satisfaction. Based on this understanding, Kano's model suggests that there are three main categories of CRs as illustrated in Figure 1.2. In the Kano diagram, the horizontal axis indicates the level of functionality of a specific CR, while the vertical axis denotes the level of customer satisfaction or dissatisfaction with a corresponding level of functionality.

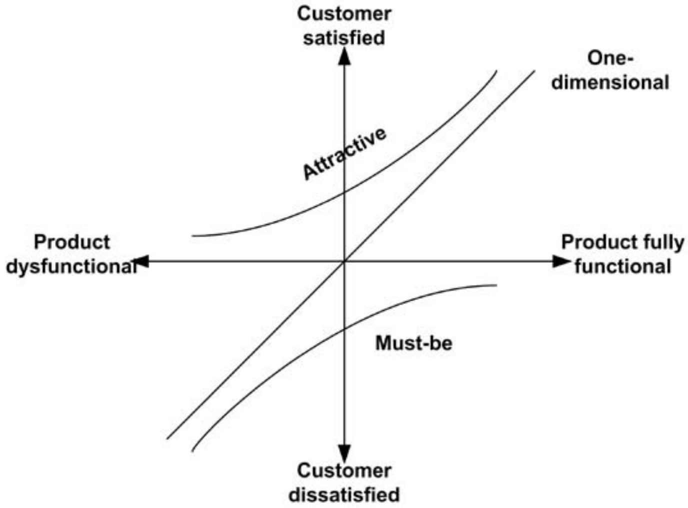

Figure 1.2 The Kano diagram [Kan84]

Must-be attributes

Customers take must-be attributes for granted when they are fulfilled. However, if the product does not meet these requirements sufficiently, customers will be very dissatisfied.

One-dimensional attributes

Regarding one-dimensional attributes, their fulfillment is positively and linearly related to the level of customer satisfaction. The higher the level of fulfillment, the higher is the degree of customer satisfaction, and vice versa.

Attractive attributes

Fulfillment of these attractive attributes will lead to a lot more than proportional satisfaction. However, the absence of these requirements does not result in any dissatisfaction because they are not expected by customers.

Table 1.2 illustrates the concept of difference Kano categories with the mobile phone as an example.

Kano Categories	Sample attributes in a mobile phone
Must-be	making phone calls, SMS
One-dimensional	display resolution, appearance, size, memory function, power solution
Attractive	music player, camera, bluetooth, FM radio, web browser, e-mail, Java game

Table 1.2 Sample CRs of different Kano categories

A must-be attribute is the most basic requirement for a mobile phone, that is, to make a phone call. Without this function, customers will regard the mobile phone as broken and will not accept the product. One-dimensional attributes are those normal requirements for a mobile phone, such as the display resolution and memory function. The larger the display resolution and the larger the memory of the mobile phone, the more satisfied the customer is. The attractive attributes are those new and innovative features of a mobile phone, such as the function of music player and camera. Customers seldom expect them in a mobile phone and therefore fulfillment of these attributes will greatly increase customer satisfaction. However, the absence of these attractive attributes will result in little customer dissatisfaction.

1.2 PROBLEMS

Quality Function Deployment (QFD) is one of the widely adopted methodologies for customer-oriented product development. It is a systematic way to translate specific customer requirements (CRs) into engineering characteristics (ECs) for design, development, implementation, and delivery of a product [Aka90]. However, one of the critical challenges of QFD implementation is the difficulties in capturing, understanding and organizing customer needs [Cri01]. Whereas traditional methods such as survey, interview, and focus group are usually adopted in QFD to collect customer needs and determine their degree of importance, the detailed methods on how to collect customer data are not clearly defined [Poe07]. Kano's model, which studies the nature of customer needs, offers a solution to this problem. It provides QFD users with an effective approach to capturing customer needs, classifying them into different categories and visualizing their relationships with customer satisfaction. For this reason, Kano's model has been integrated into QFD in the literature. However, existing research on the integration of these two methodologies is quite limited and there exist three common difficulties in this issue.

Quantification of Kano's model

Kano's model recognizes the diverse relationships between CR fulfillment and customer satisfaction. However, the model only focuses on the qualitative descriptions and analysis concerning design of Kano questionnaires, classification methods and features of various relationship curves. It is very difficult to analyze the relationship curves in a quantitative way based on the original Kano's model. Therefore, the first problem is how to quantify Kano's model to identify the relationship functions between CR fulfillment and customer satisfaction so that Kano's model can be adapted into a mathematical programming model for solving QFD optimization problems.

Integration of Kano's model into QFD

Understanding CRs accurately is a challenge for the traditional QFD analysis, and for this reason, Kano's model is often discussed and analyzed in the QFD literature. The inherent nature of Kano's model and QFD has suggested strong cohesions between them and great improvements to product development that might be obtained from the integration of these two methodologies in terms of budgets and customer satisfaction. However, how to integrate Kano's model into QFD is a major concern. Moreover, Kano's model is so famous for the Kano diagram, while its entire methodologies are far more than the diagram. Thus the problem mainly focuses on how to select the most useful information from Kano's model and to develop a step-by-step method for integrating Kano's model into QFD.

QFD optimization model

The main purpose of adopting a QFD optimization model is to determine a set of ECs of a product to maximize customer satisfaction under various cost and technical constraints. Therefore, when building a QFD optimization model, target value setting for ECs is always one of the most important elements that should be considered and discussed.

In the approach for setting EC targets proposed by Bode and Fung [Bod98], target values are expressed as the degree of attaining the target for an EC. Similarly, other authors define target values as levels of fulfillment of ECs [Fun02, Tan02, Che04 and Che05]. However, this definition of EC target values is not clear in some cases. Take the EC "lead dust generated" for a pencil as an example. It is quite difficult to determine what it would mean to optimally meet this requirement. Without some measurement scale, a target like meeting this requirement for 0.8 is meaningless. It should be noted that even if a measurement scale is available for setting EC targets, this scale can not be applied to all the ECs due to the different features of ECs in a specific product. In particular, some ECs can be regarded as continuous variables in the optimization model, such as the weight of a notebook computer, while some others are regarded as discrete ones with several feasible values, such as the CPU of the notebook computer. These two types of ECs should be treated differently when determining their target values. Therefore, a third problem identified in this research project is how to develop a uniform approach to defining and setting target values of ECs in the QFD optimization model.

1.3 RESEARCH OBJECTIVES

In order to solve the aforementioned problems, several research objectives have been established. The primary aim of the research is to develop a mathematical programming based approach that quantitatively integrates Kano's model into QFD to achieve the objective of maximizing customer satisfaction under various cost and technical constraints. The main aim of the research can be further decomposed into the following three objectives:

- To quantify Kano's model by identifying the relationship functions between CR fulfillment and customer satisfaction;
- To develop a step-by-step methodology to integrate Kano's model into QFD in a robust manner for product design and development;
- To develop a QFD mathematical programming model that integrates both quantitative and qualitative results from Kano's model into the HOQ to maximize customer satisfaction under various cost and technical constraints.

1.4 SCOPE OF THE THESIS

This research project is devoted to developing an integrative approach of QFD and Kano's model for optimizing customer-oriented product design. The remaining sections of the thesis are organized as follows.

Chapter 2 gives a comprehensive review in four sections including the concept of quality, Kano's model, Quality Function Deployment (QFD) and existing research on integration of Kano's model into QFD. The literature review has identified several research gaps, particularly in three areas including quantification of Kano's model, methodological problems in the QFD optimization model and robust integration of Kano's model into QFD.

In Chapter 3, a novel approach that integrates Kano's model into QFD optimization is proposed to optimize product design with the objective of maximizing customer satisfaction under various cost and technical constraints. The proposed integrative approach has offered solutions to the aforementioned three problems in the literature. The integrative approach is conducted in three stages including applying traditional Kano's model, conducting quantitative analysis of Kano's model and formulating the QFD optimization model.

In order to validate the proposed approach, a case study concerning the notebook personal computer design is conducted and presented in Chapter 4. Target customers of the notebook computer are university students who are a major customer segment in the notebook computer market. The proposed approach is applied to the case study by six steps: Kano customer survey, Kano survey analysis, Kano quantitative analysis, construction of the HOQ, normalization of EC values and integration of Kano's model into QFD optimization.

Finally, a conclusion is drawn in Chapter 7. Major achievements and contributions of the research project are discussed. Some recommendations are also provided for possible future development.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

QFD is a useful and practical tool that can help companies actively participate in product design and development. Since its origination in Japan in the 1960s, QFD has been successfully adopted by many companies in Japan, America and Europe. Meanwhile, its development in the research field has also spread all over the world. Many authors investigate on the methodological analysis in QFD and its applications in various industries. The integration of QFD with other methods or theories such as Kano's model, fuzzy set theory and mathematical programming techniques also gains popularity among researchers.

In this chapter, a comprehensive review is conducted on relevant theories. Firstly the concept of quality is defined to promote a general understanding of quality development from various aspects. Kano's model is then reviewed in detail by introducing the Kano diagram, the Kano questionnaire as well as further development of Kano's model and its industrial applications. Following that, there is a full discussion on the QFD literature including QFD origination and definitions, QFD basics and the methodological development of QFD optimization model. Finally the literature on integration of Kano's model into QFD is reviewed to identify possible research gaps that can be made to improve and hopefully optimize the whole process of product design and development.

2.2 THE CONCEPT OF QUALITY

Quality becomes an increasingly important concern for companies who compete in today's ever-changing socio-economic and technological environment. Companies pursue high quality in product and services in order to satisfy customer needs and maintain their loyalty. However, "high quality" product does not simply mean that the product is defect-free. Companies should be aware that quality can be defined in a number of ways. Garvin [Gar88] was the first to categorize various definitions of quality existing in the literature so as to promote a common understanding. He listed five approaches to defining quality including the transcendent; product-based, user-based, manufacturing-based, and value-based approaches.

The Transcendent Approach

The transcendent view is typified by Tuchman's definition [Tuc80]: "a condition of excellence implying fine quality as distinct from poor quality……Quality is achieving for the highest standard as against being satisfied with the sloppy or fraudulent." The difficulty with this view is that it tends to be subjective and vague, since it offers little practical guidance in defining what quality products exactly are.

The Product-based Approach

The product-based approach identifies specific product features or attributes to measure the product quality. According to Abbott [Abb55], "differences in quality amount to differences in the quantity of some desired ingredients or attribute." In other words, the presence of a favorable attribute or the absence of an unfavorable attribute would imply higher quality. This approach provides objective measurement of quality. However, a one-to-one correspondence between product attributes and quality is sometimes too simple to describe a full picture of product quality.

The User-based Approach

According to this approach, users determine the quality of goods. The product that best satisfies users' needs is considered to be of high quality. Juran [Jur88] refers the user-based approach as "fitness for use." Deming [Dem86] postulated that product quality should aim at "the needs of the customer, present and future." Feigenbaum [Fei91] also agreed that quality is defined by the customer. This user-based definition equates customer satisfaction with quality. Companies adopting this view of quality strive to design products in a way that best satisfies customer needs and wants so as to maximize customer satisfaction.

The Manufacturing-based Approach

Crosby [Cro79] described the manufacturing-based approach as "conformance to requirements." Engineers specify the product characteristics, and the more closely manufacturing can conform to those requirements, the higher the product quality is. Taguchi also held the same view of quality. The loss function he proposed attempts to measure how well the manufacturing adheres to the technical requirements by computing the cost of deviation from the target value [Tag86].

The Value-based Approach

This definition of quality has introduced the element of price. Broh [Bro82] stated that "Quality is the degree of excellence at an acceptable price and the control of variability at an acceptable cost." The value-based approach actually assumes that the purchase decisions are based on the quality and price of the product. Consumers need to make trade-off between quality and price. This approach seems not to be effective in practice since many of the attributes of quality are subjective assessments.

The above mentioned approaches define quality from different aspects, including customer needs, product attributes, manufacturing requirements and product cost. In practice, companies tend to adopt a mix of these approaches to investigate on the multi-dimensions of quality. However, in recent years, the emphasis of quality has been gradually put on catering for customer needs [Has00]. By meeting customer needs and wants through various product attributes, companies will be able to achieve customer satisfaction and maintain customer loyalty. Based on this understanding, various methods and tools are accordingly developed to help companies generate a better understanding of customer needs. Among them, Kano's model and Quality Function Deployment (QFD) are two widely-used tools to address the issue of customer focus in the product design and development process.

2.3 KANO'S MODEL

Kano's model, proposed by the Japanese professor Noriaki Kano and his colleagues, is a useful tool to understand customer needs and their impact on customer satisfaction [Kan84]. It categorizes different CRs based on how well they are able to achieve customer satisfaction. The model mainly consists of two parts: Kano diagram and Kano questionnaire. In the following section, the literature on these two parts of Kano's model and existing research on Kano's model are reviewed, respectively.

2.3.1 The Kano Diagram

The Kano diagram distinguishes three types of CRs, namely must-be, one-dimensional and attractive, as represented by three different relationship curves between customer satisfaction and CR fulfillment level in Figure 1.2.

Must-be Attributes

Must-be attributes are the basic criteria of a product required by customers represented by the lower right curve of the Kano diagram. Without these basic attributes, the product is unacceptable and customers will be extremely dissatisfied. On the other hand, as customers take these requirements for granted, their fulfillment will not increase their satisfaction. Must-be requirements sometimes are regarded as unstated or unspoken requirements, since customers may indeed be unaware of them, but they are assumed to be automatically supplied.

One-dimensional Attributes

One-dimensional attributes are depicted by the diagonal line in the Kano diagram. Their fulfillment is positively and linearly related to the level of customer satisfaction. In other words, the higher the level of fulfillment, the higher the degree of customer satisfaction, and vice versa. One-dimensional attributes are usually explicit, written or verbal requirements specified by customers. They can be identified easily and expected to be fulfilled.

Attractive Attributes

Attractive attributes represents innovations, as shown as the curved line in the upper left of the Kano diagram. These attractive requirements have the greatest influence on how satisfied a customer will be with a given product. Fulfilling these requirements will lead to a lot more than proportional satisfaction. This is because attractive attributes are neither explicitly expressed nor expected by customers. They are always beyond customers' expectation and thus can be used as creative features to attract customers and enhance their perceived value and satisfaction.

The major contribution of Kano's model just rests on identifying these three different relationships between CR fulfillment and customer satisfaction. This is because in the past the relationships between CR fulfillment and customer satisfaction are always viewed in one-dimensional terms. Kano's model complements this traditional view by identifying diverse relationships between CR fulfillment and customer satisfaction, especially these non-linear relationships associated with must-be and attractive attributes.

2.3.2 The Kano Questionnaire

The Kano diagram focuses on three primary categories of customer requirements that are have the most impact on customer satisfaction. In the Kano questionnaire, however, more detailed classification and analysis are presented. Kano and his colleague believe that CRs can be classified by the Kano questionnaire into six categories, one-dimensional (O), attractive (A), must-be (M), indifferent (I), reverse (R) and questionable (Q). The first three are the main categories that are already well illustrated through the Kano diagram. If a CR is classified as indifferent, it means that customers are indifferent to that requirement and its fulfillment or unfulfillment will not cause any increase or decrease in customer satisfaction towards the product. The other two categories indicate either a contradiction in the customer's answers to the questions (Questionable) or a reverse, or dislike of customer feel towards the requirement.

Kano's model employs a special questionnaire [Ber93] to identify relevant CRs and classify them into different categories. In a typical Kano questionnaire, customers are required to answer questions that are organized in pairs. Each pair of questions examines a CR in two different forms: functional and dysfunctional.

- *Functional form*: How do you feel if that feature is present in the product?
- *Dysfunctional form*: How do you feel if that feature is not present in the product?

Customer could answer these two different forms of questions in five ways as shown in Table 2.1. These five ways of answers illustrate customers' responses to the presence (functional form) or absence (dysfunctional form) of a product attribute (CRs). This combination of question forms is a special feature of the Kano questionnaire to classify CRs into different Kano categories, which can not be achieved through traditional survey questionnaires.

Functional form If the gas mileage is good, how do you feel?	1. I like it that way. 2. It must be that way. 3. I am neutral. 4. I can live with it that way. 5. I dislike it that way.
Dysfunctional form If the gas mileage is poor, how do you feel?	1. I like it that way. 2. It must be that way. 3. I am neutral. 4. I can live with it that way. 5. I dislike it that way.

Table 2.1 A pair of sample questions in a Kano questionnaire

Based on customers' responses to the pair of questions in the questionnaires, CRs could be classified into one of the six Kano categories mentioned previously. For example, if the customer answers, "I like it that way," to the functional form of the question "the gas mileage is good", and "I dislike it that way," to the dysfunctional form question "the gas mileage is poor", then by checking the intersection between the first row and the fifth column, an "O" can be found as illustrated in Table 2.2. It indicates that the gas mileage is a one-dimensional attribute from the point view of that particular customer.

CRs		**DYSFUNCTIONAL**				
		1. like	2. must-be	3. neutral	4. live with	5. dislike
FUNCTIONAL	1. like	Q	A	A	A	**O**
	2. must-be	R	I	I	I	M
	3. neutral	R	I	I	I	M
	4. live with	R	I	I	I	M
	5. dislike	R	R	R	R	Q

Table 2.2 Kano evaluation table

Once all the questionnaires collected from customers are checked by the Kano evaluation table, the Kano category for each CR can be identified by the most frequent response method. The method looks up the number of customer responses in different categories for each CR and tallies them in the Kano questionnaire tabulation table in Table 2.3. For each row in the tabulation matrix, one of the six categories with the highest tally indicates the dominant customer view for that attribute. For example, the highest tally of CR 3 is 13 which falls into the attractive category, this CR is then classified as an attractive (A) attribute.

CRs	A	M	O	R	Q	I	Total	Kano Category
1.	1	7	**15**				23	**O**
2.		**22**			1		23	**M**
3.	**13**		5			5	23	**A**
4.	8	1	4			**9**	23	**I**
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…

Table 2.3 Sample Kano tabulation table

2.3.3 Further Development of Kano's Model

A number of researchers have attempted to improve Kano's model in different ways. They mainly focus on some theoretical issues of Kano's model, such as the derivation of the Kano diagram, the validity and reliability of Kano's model and further classification of Kano categories, etc.

King [Kin95] proposed some general guidelines for classification of CRs. He postulated that unsolicited complaints are most often must-be attributes; one-dimensional attributes are most-often identified by surveys and attractive attributes are those developed by suppliers based on new insights and breakthroughs.

Fong [Fon96] postulated that when customer responses are evenly distributed among two or more Kano categories, it is difficult to determine the proper characterization of the requirement. Therefore, he proposed to use the self-stated importance questionnaire to complement the Kano questionnaire.

Sauerwein [Sau99] studied the validity and reliability of Kano's model, particularly the Kano questionnaire, by examining the test-retest-reliability, alternate forms and interpretation stability as well as concurrent, predictive and convergent validity. The results are supportive for Kano's model.

Berger *et al.* [Ber93] identified some inconsistencies in Kano's model as shown in Figure 2.1. They first plotted five answers of the questionnaire on the Kano diagram and then plotted lines representing all 25 combinations of answers shown in the Kano Evaluation Table. In this way, three relationship curves are derived in the diagram. They have found some inconsistency between the Kano diagram and the answers in the Kano Evaluation Table. The derived attractive curves (1-2, 1-3, 1-4) may have negative value at the dysfunctional side, while the attractive curve in the

Kano diagram consists of all positive values. There is similar inconsistency with the must-be curve.

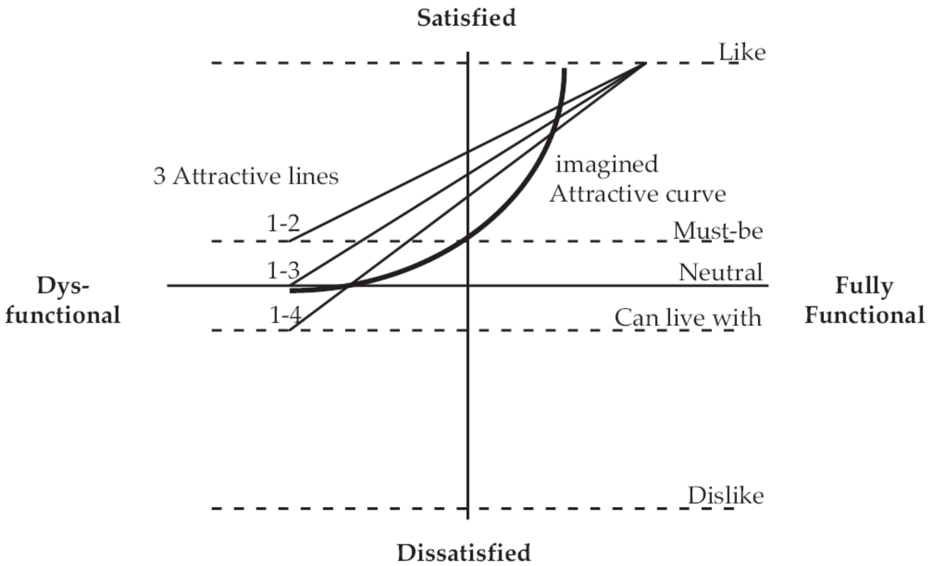

Figure 2.1 Attractive curves derived from Kano Evaluation Table [Ber93]

Yang [Yan05] refined Kano's model by considering the importance of quality attributes as defined by customers. The original Kano's model was extended to eight categories: highly attractive and less attractive, high value-added and low value-added, critical and necessary, and potential and care-free. The author further developed an importance-satisfaction (I-S) model. By integrating Kano's model and the I-S model firms can gather more valuable information for quality decisions.

The above literature on Kano's model indicates that most of its research involves solely qualitative analysis and modifications. Berger *et al*. [Ber93], on the other hand, introduced some quantitative analysis into Kano's model. They proposed to calculate two values ('Better' and 'Worse') to reflect the average impact of a CR on customer satisfaction or dissatisfaction of all customers. These two values were then named by Matzler and Hinterhuber (1998) as the extent of customer satisfaction (CS) and the extent of customer dissatisfaction (DS) for each CR based on the questionnaire results in Kano's model. These two values indicate the percentage of customers that expressed satisfaction with the existence of a certain CR (or its sufficiency), and in case of its unfulfillment, the percentage of customers expressed dissatisfaction. Based on Berger *et al*.'s work, Tontini [Ton03] further proposed some modifications of Kano's model by introducing three Customer Satisfaction Coefficients, namely SI (degree of satisfaction with existence and sufficiency), DI (degree of dissatisfaction with inexistence and insufficiency and RI (degree of dissatisfaction with existence). Berger *et al.* and Tontini's approach have improved Kano's model in understanding the impact of different CRs on customer satisfaction. However, simply calculating some index values cannot accurately reflect the diverse relationships between CR fulfillment and customer satisfaction which is a major contribution of Kano's model.

To sum up, the literature on theoretical analysis of Kano's model indicates that most of its analysis involves solely qualitative analysis and modifications of Kano's model. Some quantitative analyses have been proposed to improve Kano's model. However, these approaches still disregard the most important contribution of Kano's model, that is, the diverse relationships between CR fulfillment and customer satisfaction, especially the non-linear relationships associated with must-be and attractive attributes. Therefore, more research needs to be conducted on quantification of Kano's model and investigation on the relationship functions between CR fulfillment and customer satisfaction.

2.3.4 Applications of Kano's Model

Kano's model is widely recognized and adopted by industries and researches in the analysis of customer satisfaction. Huiskonen and Pirttilä [Hui98] applied Kano's model into the logistics customer service planning process to classify different logistics customer service requirements. Zhang and Dran [Zha02] adopted Kano's model in an exploratory investigation of customer quality expectations for designing a website. Lee *et al*. [Lee02] applied Kano's model to constructing the web-based learning environment based on students' needs and developed suitable teaching strategies for each student. Shahin [Sha04] integrated Kano's model with the failure mode and effect analysis (FMEA) to enhance the FMEA capabilities by taking customer perception into the determination of failure severity and the priority of corrective action. Kuo [Kuo04] used Kano's two-way quality model to categorize web-community service quality dimensions and their elements and understand the demands of users. Yoshimitsu *et al*. [Yos06] applied Kano's model in service engineering field to develop a new evaluation method of satisfaction which customers could gain by service. Kano's model, together with Prospect Theory, was employed to determine the "Satisfaction – Attribute Value" function in the proposed evaluation method.

Kano's model is a well-known tool for analyzing customer needs and achieving customer satisfaction. Although the application of Kano's model is comparatively limited compared with the QFD application, the literature discussed above demonstrates its advantage in understanding customer needs and developing suitable solutions for each type of customer needs to optimize the objectives in different contexts.

2.4 QUALITY FUNCTION DEPLOYMENT (QFD)

QFD is a comprehensive planning tool used to fulfill customer expectations. It is a disciplined and systematic approach to product design, process planning, engineering and manufacture. In order to gain more understanding about QFD, a comprehensive review and study on QFD is conducted including QFD origination and development, QFD concepts and basics, as well as methodological development of QFD in optimization and modeling.

2.4.1 QFD Origination and Development

QFD was originally developed in Japan as an effort to make engineers have early awareness of quality in the design process, and the idea was introduced in the 1960s to Japanese companies [Aka03]. Its further development happened in the Japanese automotive industry in the 1970s. Toyota, in particular, used it to significantly reduce development time and to deal with more complex situations, such as their solutions to the serious problem of car body rust which confronted Toyota cars for years. Toyota adopted the QFD process to identify and target at the more important contributing factors, thus resulting in the elimination of body rust during the warranty period. The application of QFD has been one of the keys to Toyota’s success [Xie03].

The introduction of QFD to America and Europe began in 1983 when the American Society for Quality Control published Akao's work “Quality Function Deployment and CWQC in Japan” in Quality Progress and Cambridge Research. Also instrumental in the introduction of QFD into the U.S was a four-day seminar delivered by Furukawa, Kogure, and Akao to about 80 quality assurance managers from prominent U.S companies. Due to the success of their competitors like Toyota, American companies began to investigate how the Japanese companies operated, thereby learning QFD. Eventually, QFD has been used in many automotive-related organizations and further spread across a wide variety of industries in U.S.A. and Western Europe. New and innovative applications of QFD were experimented by industries and businesses that were not reached before.

2.4.2 QFD Concept

The founder of QFD, Akao [Aka90], defined QFD as “a method for developing a design quality aimed at satisfying the customer and then translating the customer’s demand into design targets and major quality assurance points to be used throughout the production phase”. Sullivan [Sul86] also described QFD more concisely as “a system to assure that customer needs drive the product design and production process”. These two definitions bring out the first fundamental belief of QFD, that is, a customer-driven planning process.

Hauser and Clausing [Hau88] conceptualized QFD with a different emphasis, “quality function deployment focuses and coordinates skills within an organization, first to design, then to manufacture and market goods that customers want to purchase and will continue to purchase.” They are more concerned with the teamwork, cross-functional collaboration and company-wide communication. This was in fact another original intention of Akao’s when developing QFD.

The definition of QFD from the American Supplier Institute (ASI) attempts to include both views as two basic beliefs in QFD. It defines QFD as “a system for translating customer or user requirements into appropriate company requirements at every stage from research, through product design and development, to manufacture, distribution, installation and marketing, sales, and service."

2.4.3 QFD Basics

Generally, the QFD structure is presented as a system of matrices, charts, tables and other diagrams. There are two popular models illustrating the QFD process: the "Matrix of Matrices" developed by Dr. Akao [Aka90], and the four-phase model developed by Hauser and Clausing [Hau88]. The four-phase model is probably the most commonly used one in the QFD process. Due to its popularity, the four-phase model is illustrated here in detail. It divides a typical product development process into four phases with four matrices as shown in Figure 2.2.

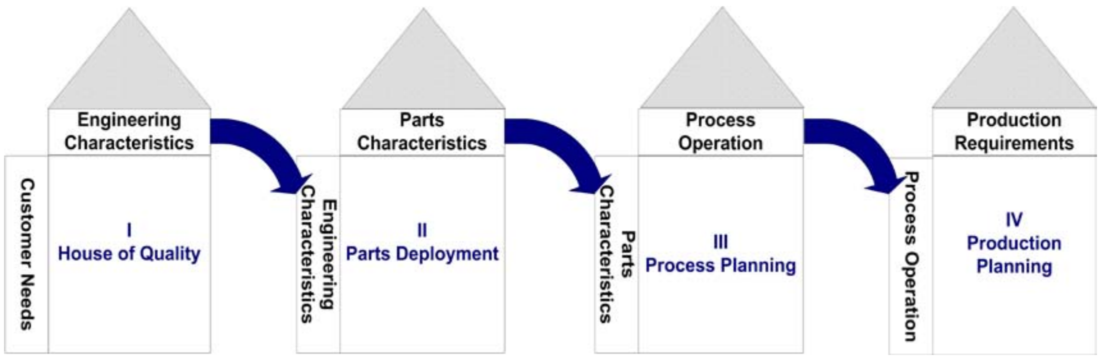

Figure 2.2 The Four-Phase Model of QFD [Hau88]

The first phase is to collect customer needs for the product (or customer requirements, customer attributes) called WHATs and then to transform these needs into engineering characteristics (or technical requirements, product design specifications, technical measures) called HOWs. Customer needs are often referred to as the Voice of Customer (VOC). The second phase transforms the prioritized technical measures in the first phase into part characteristics, called Part Deployment. Key part characteristics are transformed in the third phase, called Process Planning, into process parameters or operations that are finally transformed in the fourth phase called Production Planning into production requirements or operations.

The House of Quality (HOQ), sometimes also called A-1 Matrix, is the most commonly used matrix in the QFD methodology. It is adopted in the first phase of QFD process translating the general customer requirements into specific final product characteristics. The fundamental belief of the HOQ is that products should be designed according to customers' desires and tastes. Thus, marketing people, design engineers, and manufacturing staff must work closely together from the time of product conceptualization. It can be seen that in addition to meeting customer needs and wants, the HOQ also provides a means for cross-functional planning and communication [Hau88].

A typical HOQ comprises six main parts as described in Chapter 1. Although the HOQ's contents are different in various presentations, more detailed description through "sub-parts" in Figure 2.3 provides a nearly full illustration of key elements in the HOQ [Cha02].

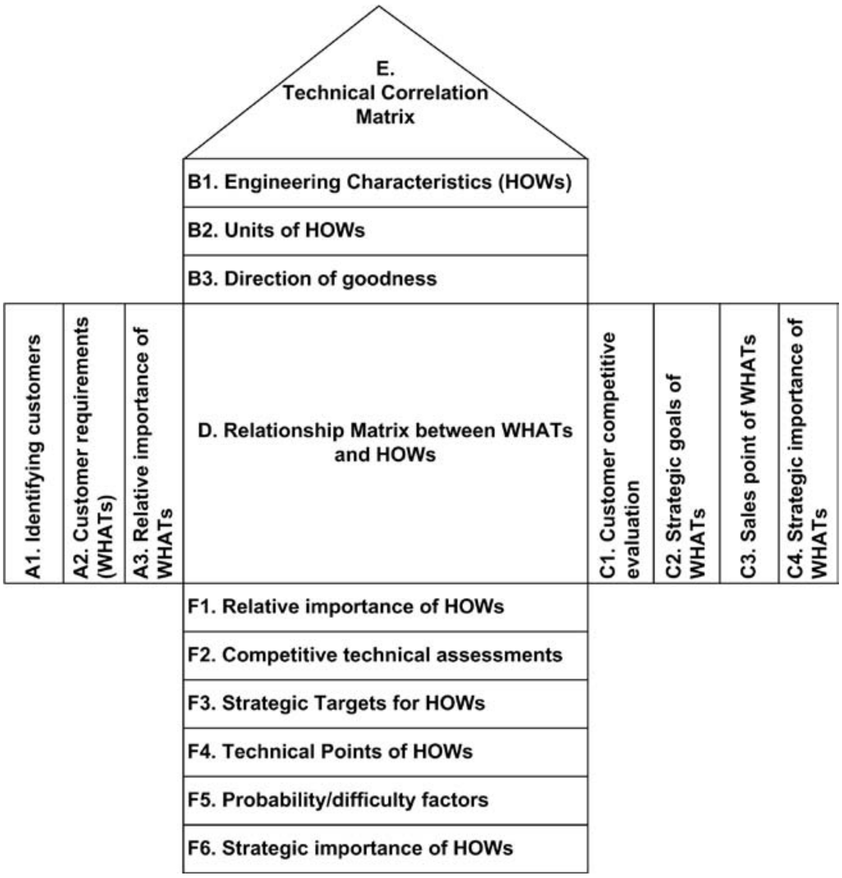

Figure 2.3 House of Quality (HOQ): detailed description [Cha02]

Part A: Customer Requirements (WHATs)

Part A of the HOQ is the description of customer needs and expectations. In addition to identifying CRs for the product concerned, it is also important to determine importance weightings of CRs. The simplest method of prioritizing CRs is based on a point scoring scale [Gri93], such as (0, 1, 3, 5) and (0, 1, 3, 9) to represent the degree of importance of CRs. Another popular prioritization method is Analytical Hierarchy Process (AHP) [Saa80] adopted by many authors [Fuk93, Lu94, Arm94 and Par98] to determine the importance of CRs. AHP is a widely-used multi-criteria decision-making technique that employs both qualitative and quantitative approach to solve the prioritization problem [Che01]. Moreover, QFD process may involve various inputs in the form of linguistic data, which often exhibit some form of imprecision, vagueness and uncertainty [Zad78]. To deal with imprecise information quantitatively, fuzzy set theory has also been combined with the AHP approach by some researchers to determine the importance weights of CRs [Büy04, Büy07, Fun98, Van01, Kwo03].

Part B: Engineering Characteristics (HOWs)

Part B lists and structures the engineering characteristics (HOWs) identified by the product development team. Technical measures could be methods, company measures, design requirements, substitute quality characteristics, and engineering characteristics, which can be related to and measure the customer needs (WHATs). The units and directions of goodness or improvements of these HOWs are also determined to facilitate further analysis and deployment.

Part C: Planning Matrix

The previous part is a listing of qualitative customer needs, while this part of planning matrix is actually a repository of quantitative data about customer needs. The main purpose of this part is to evaluate the company's product and compare it with similar products from its main competitors in terms of products' performance on customer needs. Based on these comparative evaluations, the company could set strategic goals for its products to better satisfy customer needs. Sales points may also be derived to indicate the company's core competencies and external opportunities. The final rank order in this part is the strategic importance of customer needs, which can be computed from the information in both Part A and Part B.

Part D: Relationship Matrix Between WHATs and HOWs

The relationship between each WHATs and HOWs are identified in this part. Usually there are four types of relationships, i.e. no relationship, weak relationship, medium relationship and strong relationship. Usually, two sets of measurement scale, (0, 1, 3, 5) or (0, 1, 3, 9), can be employed to quantify the above four relationships. For example, strong relationship = 5 (or 9), medium relationship = 3, weak relationship = 1. However, relying on human judgment, the functional relationships tend to be determined in a subjective and non-systematic way. Especially when the HOQ contains a large number of CRs, it is quite difficult to identify those functional relationships using human knowledge. Wasserman [Was93] proposed a normalization procedure to transform the raw relationships between CRs and ECs obtained from the HOQ into normalized relationships which can more accurately reflect the extent to which the fulfillment of ECs will contribute to customer satisfaction.

Part E: Technical Correlation Matrix

The technical Correlation Matrix is an assessment of which HOWs are interrelated and how strong these relationships are through engineering analysis and experience. According to Cohen [Coh95], this part is probably the most under exploited part of QFD. Usually five types of technical correlations or impacts are identified in QFD: strong positive impact, moderate positive impact, no impact, moderate negative impact, and strong negative impact. Similar to Part D, a set of measurement scale such as (0, 1, 3, 5) or (0, 1, 3, 9) could be used to quantitatively represent the said impact.

Part F: Technical Matrix

The technical Matrix contains a large amount of technical information that is related to both customer needs and engineering characteristics. It evaluates the relative importance of each technical measure. Similar to the customer competitive evaluations in Part B, competitive technical assessment concerns benchmarking the company's performance with its competitors. However, the focus is on the technical measures (HOWs). Then, strategic targets and technical points for HOWs can be set and probability/difficulty factors are identified. Based on the above information, a final importance of HOWs is computed and more important HOWs are selected to enter into the next phase of QFD for further analysis and deployment.

2.4.4 QFD Optimization Model

A complete HOQ comprises six main parts including CRs, ECs, relationships between CRs and ECs, correlations among CRs, benchmarking information, and technical information. When introducing optimization and modeling into QFD, the main purpose is to integrate all the information in the HOQ to optimize the overall customer satisfaction with a product. It takes into account multiple issues including prioritization of CRs, relationships between CRs and ECs, correlations among ECs and various design constraints. The emphasis is, however, on the optimization of customer satisfaction by considering trade-offs between various constraints such as costs, time and human resources. A number of methods have been employed to solve the QFD optimization problem including integer programming, linear programming and some other programming techniques. In the following parts, QFD optimization models using different programming techniques will be reviewed in detail.

2.4.4.1 Integer Programming

Integer programming is a commonly used approach for solving the optimization problem. When it is applied to solve the QFD optimization problem, the core concept is that it chooses some ECs to provide the best objective value under certain constraints. Wasserman [Was93] developed the first mathematical programming model to optimize product design associated with costs and customer satisfaction. The model was a 0-1 integer programming formulation that focused on the prioritization of ECs for the decision of resource allocation rather than determining the target fulfillment levels of ECs. Correlations among ECs were not incorporated into this model. Park and Kim [Par98] improved Wasserman's model by proposing a quadratic integer programming model in which the correlations among ECs were incorporated through cost constraints. Kreng and Lee [Kre04] also adopted integer programming in their QFD optimization model. They applied QFD into the modular product design to explore a set of ECs which combines customer needs, company development strategies and designers' preferences to select proper modular drivers. Integer programming was used to establish the final configuration. From the above models proposed by different authors, it can be seen that integer programming is useful to select an optimal set of ECs for product design. However, its drawback lies in the fact that it cannot determine the specific level of fulfillment for each EC to achieve the optimal solution. Therefore, integer programming is not suitable for solving certain QFD problems such as target value setting for ECs.

2.4.4.2 Linear Programming

The most widely used method in QFD optimization model is linear programming. It is adopted to allocate resources to different ECs in order to maximize the overall customer satisfaction [Lai06]. There are many publications dealing with this topic. Moskowitz and Kim [Mos97] developed a decision support system prototype named QFD optimizer that is based on a linear programming model to help users find improved designs yielding higher customer satisfaction. Askin and Dawson [Ask00] presented a linear programming model for determining the optimal setting of ECs based on the value functions constructed to capture customer preferences. Fung *et al.* [Fun03] formulated a linear QFD planning model to determine the attainment of ECs by allocating resources among ECs with a view to achieve maximized overall customer satisfaction. The linear model takes into account the technical and resource constraints as well as the impact of the correlation among ECs and is solved by the heuristics-combined simplex method. Chen *et al*. [Che05] proposed a fuzzy-regression-based linear programming model to determine target values for a set of ECs, taking into account the inherent fuzziness in the relationships between CRs and ECs and the correlations among ECs, financial factors and customer expectations among the competitors in product development. Lai *et al.* [Lai06] proposed QFD optimization model using the linear physical programming technique to maximize overall customer satisfaction in product design. The model provided an effective way to find the optimal results, since it avoided the need to specify an importance weight for each objective in advance.

It is true that linear programming is a useful method to solve the QFD optimization problem. Some difficulties, however, exist in the real practice of QFD planning [Lai05]. The first problem is associated with the value of ECs. In linear programming, the values of ECs are often assumed to fall into a continuous range. Any value in the range could be a possible solution. However, due to technical constraints, certain ECs can only adopt several discrete values instead of a continuous range. Take the RAM of a computer as an example. There is no computer with the RAM of 100MB or 200MB, because the RAM size usually takes the value of 128, 256 or 512 MB. This is not a continuous range but some discrete values. In such a situation, it raises certain difficulties in using linear programming, since the optimal solution obtained may not be practical in the real product design. Another problem is that it is difficult to identify the relationships between CRs and ECs accurately. The objective function of linear programming in QFD is usually set to maximize the overall customer satisfaction. Then the relationships between customer satisfaction and ECs should be clearly defined to find an optimal set of ECs. Unfortunately, those relationships sometimes are difficult to represent, which in turn cause the inconvenience of using linear programming in QFD.

2.4.4.3 Other Programming Techniques

Other programming techniques are also adopted in the QFD optimization model including goal programming, non-linear programming and dynamic programming.

Goal programming also gains popularity among researchers for QFD optimization. It is postulated that goal programming is a generalization of linear programming to handle multiple, normally conflicting objective measures. In the context of QFD, goal programming was often used to determine the fulfillment levels of ECs with the aim of achieving multiple goals such as customer satisfaction, cost and technical difficulty of ECs. Karasak *et al.* [Kar02] presented a zero-one goal programming model to select important ECs by taking into account multiple goals including the importance levels of ECs, cost budget, extendibility level and manufacturability level. The model also considers the interrelationships among CRs and ECs by analytical network process (ANP) to determine the importance level of ECs. Chen and Weng [Che04] developed a fuzzy goal programming model to determine the fulfillment levels of ECs with multiple objectives: maximizing customer satisfaction, minimizing cost and technical difficulty. Differing from existing fuzzy goal programming models, the coefficients in the proposed model are also fuzzy in order to expose the fuzziness of the linguistic information. Fung *et al.* [Fun05] presented a hierarchical framework for product planning. Firstly, the least squares method was incorporated into fuzzy regression to investigate the functional relationships between CRs and ECs. Following that, a fuzzy expected value-based goal programming model was proposed to specify target values of ECs.

Non-linear programming is also frequently adopted in the QFD optimization model. Non-linear programming has the advantage of considering non-linear functions or relationships in the model. Dawson and Askin [Daw99] proposed a non-linear mathematical program to determine the optimal target values for ECs as a function of elicited customer value functions, engineering development and production costs as well as the development time constraints. Fung *et al.* [Fun02] proposed a non-linear fuzzy model to incorporate the resource factors and the attribute correlations into QFD planning. In this model, the concepts of the achieved attainments and planned attainments for ECs, as well as the corresponding primary costs, planned costs and actual costs are introduced to account for the impact of attribute correlations. Solutions to the model were obtained using a parametric optimization method or a hybrid genetic algorithm. Piedras *et al.* [Pie06] developed a non-linear programming model with multiple objectives. Using the concurrent engineering approach, the proposed model could lead to simultaneous optimal solutions and generates as many efficient solutions as possible.

Dynamic programming is also adopted for QFD optimization recently. Dynamic programming is a useful mathematical technique developed especially for solving problems exhibiting the properties of overlapping sub-problems and optimal substructure. It provides a systematic procedure for determining the optimal set of interrelated decisions [Lai05]. This feature of dynamic programming fits quite well the situation in QFD planning in which a set of ECs are selected and their optimal values are determined under various constraints to maximize the overall customer satisfaction. Lai *et al.* [Lai05] proposed a dynamic programming approach to solve the QFD optimization problem in which resources are allocated to ECs one by one. According to the dynamic programming algorithm, each EC can be regarded as a stage. Recursive relationships among stages are then established. The solution procedure starts at the first stage and moves forward stage by stage. The optimal solution for the entire problem can be found at the final stage. Compared with other optimization methods, the dynamic programming method requires less information and the optimal results are more reasonable.

2.5 INTEGRATION OF KANO'S MODEL INTO QFD

One of the critical challenges of QFD implementation is the difficulties in capturing, understanding and organizing customer needs [Cri01]. The literature on QFD indicates that traditional methods such as surveys, interviews, and focus groups are usually adopted in QFD to collect customer needs and determine their degree of importance. However, the detailed methods on how to collect customer data are not clearly defined [Poe07]. Kano's model, which studies the nature of customer needs, provides a new way for QFD users to obtain and understand customer needs. For this reason, Kano's model is associated with QFD in the literature as the starting point of the QFD process to collect and analyze customer needs.

Matzler and Hinterhuber [Mat98] proposed a methodology, based on Kano's model, to structure customer needs into different groups and to assess their strategic importance by calculating CS and DS values. This categorization of customer needs is then used as a basis for QFD analysis. Tontini [Ton03] proposed some modifications of Kano's model by introducing three Customer Satisfaction Coefficients and then integrated the modified Kano's model into the planning matrix of QFD, with a case study to demonstrate the application of the proposed integration approach [Ton07]. Sireli *et al*. [Sir07] further advanced Matzler and Hinterhuber's approach by including a widely accepted scoring method and a statistical significance test for integrating Kano results into QFD. However, these integration approaches remains to be qualitative descriptions of the QFD process and Kano's model with little quantitative analysis involved.

Shen and Tan [She00] proposed an integrative approach of incorporating Kano's model into the planning matrix of QFD to help accurately and deeply understand customer needs. Based on Kano's model analysis, an approximate transformation function was developed to adjust the improvement ratio of each CR. The adjusted improvement ratio was then multiplied by the raw importance of each CR to determine the final importance of CRs in QFD. However, it should be noted that Shen and Tan's approach tends to be subjective and vague, since the selection of Kano parameters for different categories in the transformation function basically depends on QFD practitioners' experience and knowledge.

Lai *et al*. [Lai04, Lai07] developed a mathematical programming model to optimize product design using QFD and Kano's model with a case study on personal computer design. Kano's model is integrated into the QFD model by providing the CS and DS values to reflect the contribution of different CRs to customer satisfaction. Lai *et al*.'s approach improves the traditional integration approach by establishing a mathematical programming model to optimize product design. Despite the utilization of customer satisfaction and dissatisfaction coefficients, it still presupposes that different CRs influence customer satisfaction similarly in a linear pattern. As many traditional QFD optimization models suggest [Was93, Par98, Fun03, Che05], the overall customer satisfaction (S) is represented as a linear additive value function of the degree of fulfillment (y_i) of different CRs [Poe07].

$$S = \sum_{i=1}^{m} w_i y_i \text{ (}w_i\text{: importance weightings of CRs)}$$

However, as Kano's model suggests, the contributions to customer satisfaction by different CRs vary. Fulfilling customer expectations to a greater extent does not necessarily guarantee a higher level of customer satisfaction. The relationships between CR fulfillment and customer satisfaction, especially the nonlinear relationships, have not been fully recognized in Lai *et al*.'s approach and those traditional QFD optimization models.

2.6 SUMMARY

In this chapter a comprehensive literature review has been conducted in four sections including the concept of quality, Kano's model, QFD and integration of Kano's model into QFD.

The concept of quality can be defined by a number of different approaches, including the transcendent; product-based, user-based, manufacturing-based, and value-based approaches. In practice, companies tend to adopt a mix of these approaches to investigate on the multi-dimensions of quality. In recent years, the emphasis of quality has been gradually put on the user-based approach, that is, catering for customer needs [Has00]. By meeting customer needs through various quality attributes, companies will be able to achieve customer satisfaction and maintain customer loyalty.

Due to the growing concern on customer needs, several customer-driven quality engineering tools such as Kano's model and QFD have been widely adopted. Kano's model manages to map diverse relationships between CR fulfillment and customer satisfaction, especially these non-linear relationships associated with must-be and attractive attributes, in addition to the one-dimensional relationship from the traditional view. Although Kano's model is highly recognized and widely adopted in the quality engineering field, most of its analysis remained to be the qualitative descriptions of the relationship curves. There is little research on the quantification of

Kano's model and investigation on the relationship functions between CR fulfillment and customer satisfaction.

Regarding QFD, there is extensive research concerning its methodological analysis. Still some problems exist related to the QFD optimization model. First, traditional QFD optimization models usually presume that individual CRs influence overall customer satisfaction similarly in a linear pattern [Poe07], giving little attention to the nuances of different CRs. Second, in the traditional QFD models, EC values are often assumed to fall into a continuous range. Any value in the range could be a possible solution. However, due to technical constraints, certain ECs can only adopt several discrete values instead of a continuous range.

A number of researchers also attempted to devise a step-by-step approach to integrate Kano's model into QFD for product design. However, their approaches tend to be qualitative descriptions of the two methodologies with little quantitative analysis involved. Moreover, the non-linear relationships between CR fulfillment and customer satisfaction, which is the major contribution of Kano's model, are not given sufficient attention in the QFD literature. A more robust quantitative integration of Kano's model and QFD is needed.

In the next chapter, an integrative approach of QFD and Kano's method is proposed to solve the above mentioned problems. The integrative approach proposes a new way to extract quantitative information from Kano's model and transfer the information into QFD to formulate a mathematical programming model for solving the optimization problem.

CHAPTER 3

QFD OPTIMIZATION WITH KANO'S MODEL

3.1 THE INTEGRATIVE APPROACH

QFD is a well-known technique that provides a structured framework to incorporate the "voice of the customer" into product design. Kano's model is a useful tool to capture customer needs and understand their impact on customer satisfaction. These two methodologies have been associated together in the literature due to their primary focus on customer needs. The integration of Kano's model and QFD can help companies assure that critical customer needs have been identified and translated into product design. Consistent with this thought, an integrative approach of QFD and Kano's model for optimizing customer-oriented product design is proposed in this chapter. The framework of the integrative approach is illustrated in Figure 3.1.

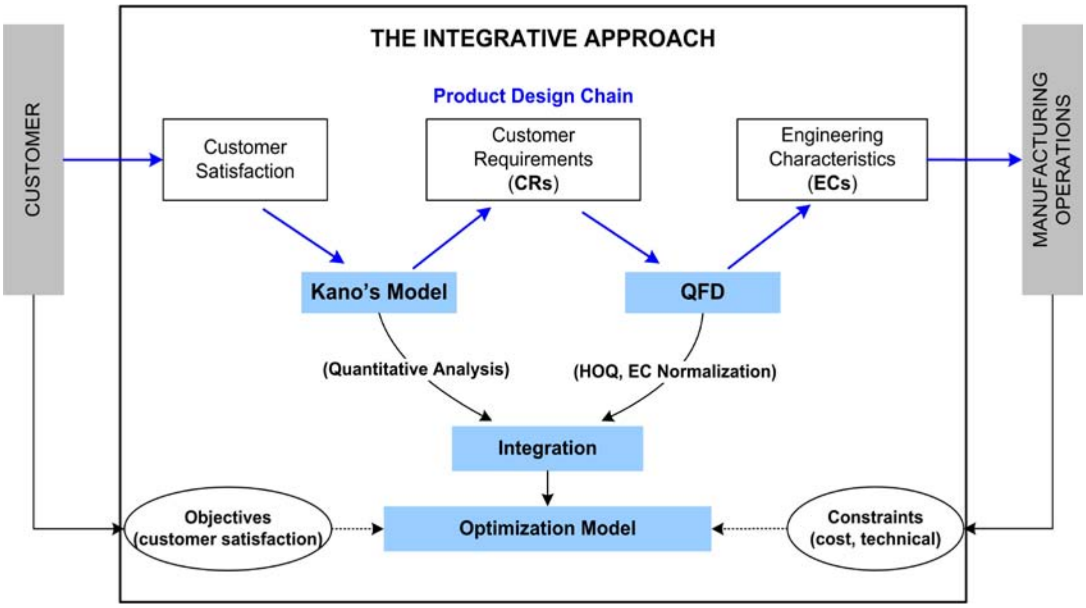

Figure 3.1 The framework of the integrative approach

As illustrated in Figure 3.1, the integrative approach has built a bridge between customers and manufacturing operations in the product design process through integrating Kano's model into QFD. It follows the product design chain, starting with dividing overall customer satisfaction into individual customer satisfaction achieved by different CRs through Kano's model, and then translating CRs into a set of ECs for manufacturing operations by adopting the QFD analysis. The results from Kano's model and QFD analysis are then integrated through quantitative analysis of Kano's model as well as building the QFD and performing EC normalization, respectively. Finally a QFD optimization model is established to determine optimal values for selected ECs with the objective of maximizing customer satisfaction from customer perspective under various cost and technical constraints set by the manufacturing operations.

The proposed integrative approach consists of three stages including applying traditional Kano's model, conducting quantitative analysis of Kano's model and formulating the QFD optimization model. The overall road map of the proposed approach is illustrated in Figure 3.2.

The integrative approach starts with applying traditional Kano's model in Stage 1. This stage discusses first, conducting preliminary study, developing and administrating the Kano questionnaire, as well as analyzing questionnaire results by Kano's model. Based on the survey results from Stage 1, quantitative analysis of Kano's model is then conducted in Stage 2 to identify relationship functions between customer satisfaction and CR fulfillment. The quantitative results from Kano's model are then transferred into Stage 3 for proper integration with QFD and formulation of a QFD optimization model. The final results demonstrate the optimal product design that maximizes customer satisfaction under various constraints. Not only has the fulfillment level been determined for each EC, but also specific EC technical value corresponding to the fulfillment level of each CR is identified. CR fulfillment and customer satisfaction level have also been calculated to demonstrate how the optimal design performs from the point of customers' view.

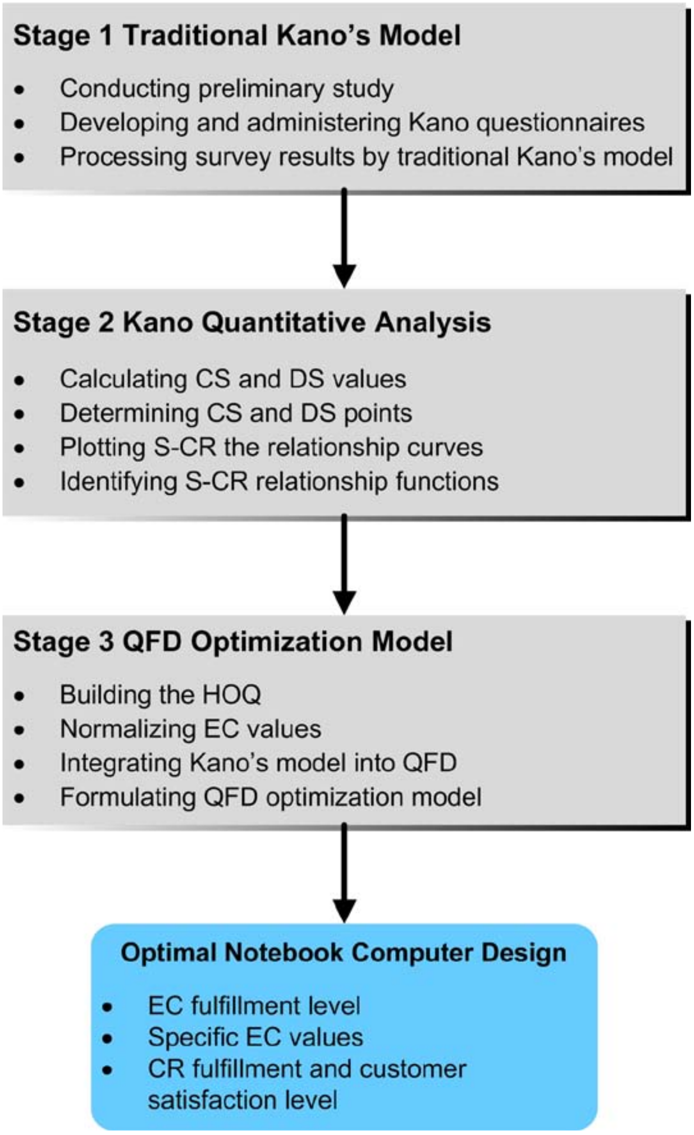

Figure 3.2 Overall procedure of the integrative approach

3.2 TRADITIONAL KANO'S MODEL

Traditional Kano's model discussed in Chapter 2 is conducted as the first stage of the proposed approach. It mainly concerns conducting preliminary study, developing and administrating the Kano questionnaire, and analyzing questionnaire results by the classification method in Kano's model. The preliminary study intends to generate a list of potential requirements of a product for developing the Kano questionnaire. The Kano questionnaire forms functional and dysfunctional questions about each requirement in the list. Following that, the questionnaire is distributed to target customers to investigate on their responses to these requirements of a product. Once all the questionnaires have been collected back, the traditional Kano's model is applied to analyze the questionnaire data, particularly, to determine the Kano category for each CR by the most frequent response method. These survey results from Stage 1 are then transferred into Stage 2 for further analysis.

Figure 3.3 illustrates how to determine the Kano category for a CR according to customer responses in the Kano questionnaire. This classification process will not be discussed in detail here since it follows the traditional analysis in Kano's model which has already been well elaborated in Chapter 2. The following sections will focus on discussing the major contribution of the research, that is, quantitative analysis of Kano's model in Stage 2 and QFD optimization model in Stage 3.

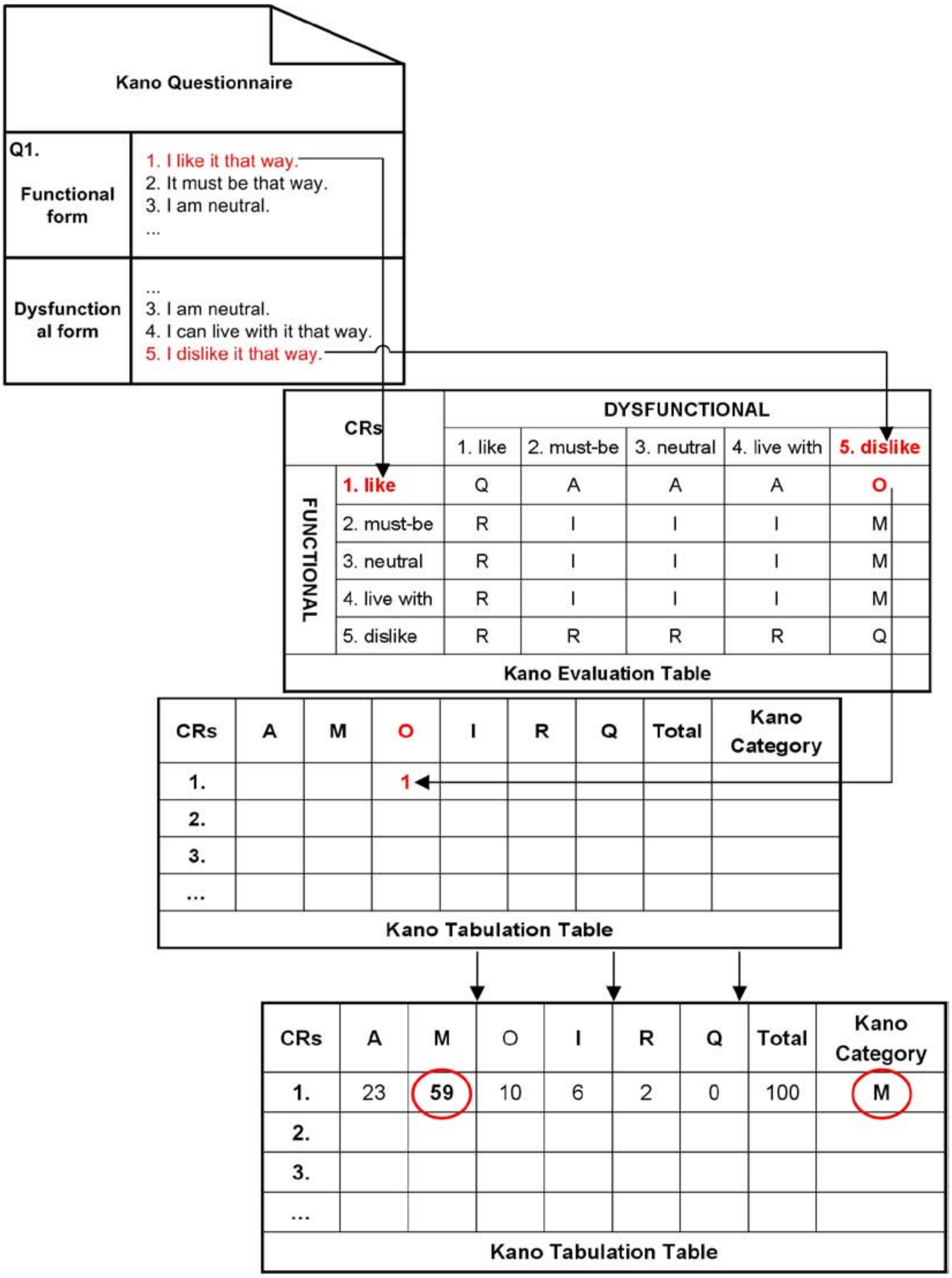

Figure 3.3 Process of Kano classification in Stage 1

3.3 QUANTITATIVE ANALYSIS OF KANO'S MODEL

Based on the survey results from the Kano questionnaire in Stage 1, quantitative analysis of Kano's model is then conducted in Stage 2 by the following four steps: calculating CS and DS values, determining CS and DS points, plotting the relationship curves between customer satisfaction and CR fulfillment (S-CR) and identifying S-CR relationship functions as illustrated in Figure 3.4. The quantitative analysis starts with processing survey results from the Kano questionnaire, and then proceeds to apply the derived results to the Kano diagram, finally results in the refined relationship curves in the Kano diagram which have removed the inconsistencies problem identified by Berger *et al.* [Ber93] and the relationship functions between CR fulfillment and customer satisfaction. In this way, Kano's model has been quantified for further analysis in QFD optimization model.

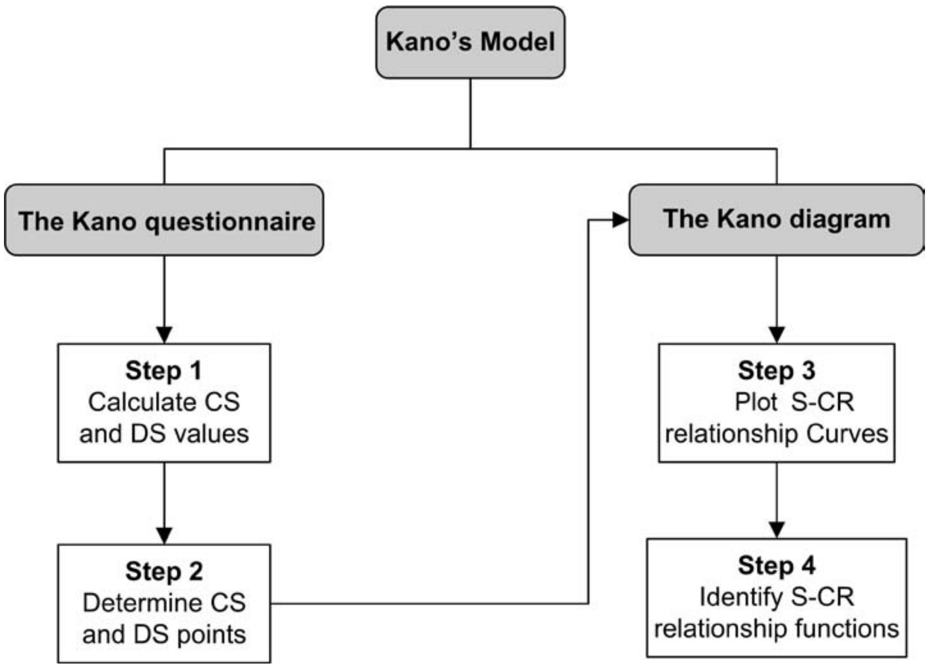

Figure 3.4 Process of Stage 2: Quantitative analysis of Kano's model

3.3.1 Calculating CS and DS values

Apart from classification results, Berger *et al.* [Ber93] identified two important values from the Kano questionnaire for quantitative analysis: the extent of customer satisfaction (CS) and the extent of customer dissatisfaction (DS). CS indicates that to what extent customer satisfaction will be increased if the company is good at that CR. DS just indicates the opposite, to what extent customer dissatisfaction will be increased if the company is not competitive in that CR. These two values are calculated by Equation (3.1) and (3.2) where f_A represents the number of customer responses as attractive attributes, and so are f_O for one-dimensional, f_M for must-be and f_I for indifferent attributes.

$$CS_i = \frac{f_A + f_O}{f_A + f_O + f_M + f_I} \tag{3.1}$$

$$DS_i = -\frac{f_O + f_M}{f_A + f_O + f_M + f_I} \tag{3.2}$$

Table 3.4 illustrates some examples on how to calculate CS and DS values for three main types of CRs. Indifferent, reverse and questionable attributes are not included into the analysis due to their low impact on customer satisfaction. For example, the CS and DS values of CR 1 are calculated as follows. Similarly the CS and DS values for CR 2 and CR 3 are calculated as shown in Table 3.1.

$$CS_1 = \frac{76+10}{76+10+6+3} \approx 0.91 \text{ and } DS_1 = -\frac{10+6}{76+10+6+3} \approx -0.17$$

CRs	A	O	M	I	Kano Category	CS	DS
1	76	10	6	3	**A**	0.91	-0.17
2	8	81	4	1	**O**	0.95	-0.90
3	4	13	69	7	**M**	0.18	-0.88

Table 3.1 Calculation of CS and DS values

3.3.2 Determining CS and DS Points

In the previous step, two important values CS and DS are calculated. One problem in adopting CS and DS values into quantitative analysis is the vagueness in defining what are good or bad performances for certain CRs. When the values of CS and DS are defined, the terms "a good performance" or "a bad performance" are not specified or quantified. It would be more appropriate if the values of CS and DS can be defined together with their corresponding quantified level of fulfillment for each CR. In order to solve the problem, two assumptions about CS and DS values have been made below.

- If the company has achieved a good performance for a CR, the fulfillment level of that CR is assumed to be 1, that is, fully fulfilled.
- If the company fails to deliver a CR, the fulfillment level of that CR is set to be 0, that is, a complete unfulfillment.

Based on these two assumptions, two points named CS and DS points can be defined accordingly. CS point of a CR expressed as (1, CS_i) is the extent of customer satisfaction when that CR is fully fulfilled, that is, the fulfillment level of the CR is equal to 1. DS point of a CR expressed as (0, DS_i) is the extent of customer dissatisfaction when that CR is not provided, that is, the fulfillment level of the CR is equal to 0. By incorporating these two points into the original Kano's model, the relationships between customer satisfaction and CR can be quantified in a more precise way.

Take the CRs in Table 3.1 as an example to illustrate how to determine the CS and DS points. It can be seen that the CS and DS values obtained from the Kano questionnaire can be further used for determining the CS and DS points for each CR as shown in Table 3.2.

CRs	**Kano Category**	**CS**	**DS**	**CS Point (1, CS_i)**	**DS Point (0, DS_i)**
1	A	0.91	-0.17	(1, 0.91)	(0, -0.17)
2	O	0.95	-0.90	(1, 0.95)	(0, -0.90)
3	M	0.18	-0.88	(1, 0.18)	(0, -0.88)

Table 3.2 Determination of CS and DS points

3.3.3 Plotting the S-CR Relationship Curves

After determining the CS and DS points, the relationship curves between customer satisfaction and CR fulfillment (S-CR) can be plotted in Figure 3.5. The horizontal axis represents the fulfillment level of CRs ranging from 0 to 1. The vertical axis represents the customer satisfaction scale ranging from -1 to 1 where the value of CS falls into the positive range of the vertical axis, while the value of DS is in the negative range. Take the CRs in Table 3.6 as an example to illustrate how to plot the S-CR relationship curves. The CS and DS points of CR 1 are (1, 0.91) and (0, -0.17), respectively. Since CR 1 is an attractive attribute, its relationship curve therefore follows the shape of an exponential curve that passes its CS and DS points. Using a similar approach, the relationship curves for one-dimensional (CR 2) and must-be (CR 3) attributes can be plotted accordingly.

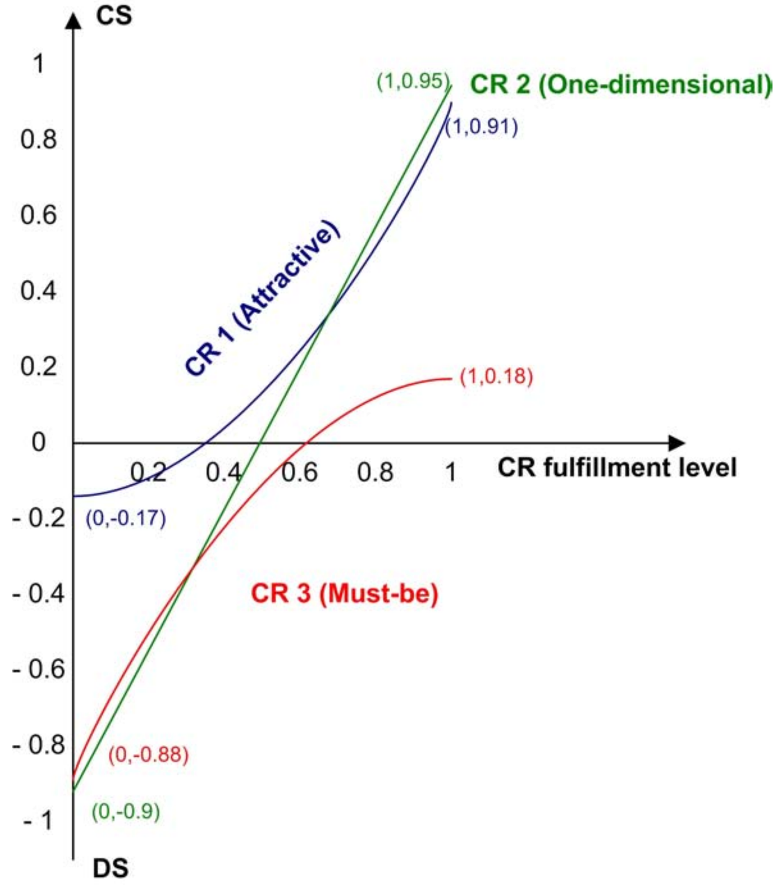

Figure 3.5 S-CR relationship curves for attractive, one-dimensional and must-be attributes

The refined S-CR relationship curves have removed the inconsistency problem identified by Berger *et al*. [Ber93]. The refined attractive curve may have a negative value at the dysfunctional side of the CR fulfillment scale depending on whether its

DS value is smaller than 0. Similarly, the refined must-be curve may have a positive value at the functional side of the CR fulfillment scale depending on whether CS value is larger than 0. Meanwhile, the CS and DS values of CRs are directly derived from the questionnaire results which conform to the answers in the Kano Evaluation Table. Therefore, the refined S-CR relationship curves have eliminated the possible inconsistencies in Kano's model and depicted the S-CR relationships more precisely.

3.3.4 Identifying S-CR Relationship Functions

After plotting the S-CR relationship curves in Figure 3.5, the next step is to approximately quantify the relationships between customer satisfaction and CR fulfillment by an appropriate function. Generally speaking, the S-CR relationship function can be expressed as $s_i = f\,(y_i, a, b)$, where s_i denotes the degree of individual customer satisfaction achieved by CR i, y_i denotes the level of fulfillment of CR i ranging from 0 to 1, and a, b are adjustment parameters for different Kano categories of CRs. The following discussion of Stage 2 will focus on the way to determine the S-CR functions for the three main types of CRs.

One-dimensional Attribute

Regarding the one-dimensional CRs, the relationship curve can be uniquely identified, since for any two distinct points, there is one line and only one line through them. The relationship function can be expressed as

$$s_i = a_1 y_i + b_1 \tag{3.3}$$

where a_1 is the slope of the straight line and b_1 is the value of DS where the value of the CR is equal to 0. Substituting the CS and DS points, that is, (1, CS_i) and (0, DS_i), into the equation, it gives that

$$a_1 = CS_i - DS_i\,,\; b_1 = DS_i \tag{3.4}$$

Therefore, the S-CR function for one-dimensional attributes is:

$$S_i = (CS_i - DS_i)y_i + DS_i \tag{3.5}$$

Attractive Attribute

The S-CR function of attractive attributes can be estimated by an exponential function as

$$s_i = a_2 e^{y_i} + b_2 \tag{3.6}$$

Similar to the case of one-dimensional attributes, a_2 is a parameter for adjusting the slope of the curve and b_2 is for adjusting the vertical level of the relationship curve in the Kano diagram. Substituting the CS and DS points into the equation gives that

$$a_2 = \frac{CS_i - DS_i}{e-1}\,,\; b_2 = -\frac{CS_i - eDS_i}{e-1} \tag{3.7}$$

Therefore, the S-CR function for attractive attributes is:

$$S_i = \frac{CS_i - DS_i}{e-1} e^{y_i} - \frac{CS_i - eDS_i}{e-1} \tag{3.8}$$

Must-be Attribute

The S-CR function of must-be attributes can also be estimated by an exponential function which is expressed as $s_i = a_3(-e^{-y_i}) + b_3$. Similarly, a_3 is a parameter for adjusting the slope of the curve and b_3 is for adjusting the vertical level of the relationship curve in the Kano diagram. Substituting the CS and DS points, (1, CS_i) and (0, DS_i), into the equation gives that

$$a_3 = \frac{e(CS_i - DS_i)}{e-1},\ b_3 = \frac{eCS_i - DS_i}{e-1} \tag{3.9}$$

Thus, the S-CR function for must-be attributes is:

$$S_i = -\frac{e(CS_i - DS_i)}{e-1} e^{-y_i} + \frac{eCS_i - DS_i}{e-1} \tag{3.10}$$

Integrating these three cases together, the S-CR function can be expressed in a general form: $s_i = af(y_i) + b$ where $f(y_i)$ is the basic function determining the shape of the relationship curve, while *a*, *b* are two adjustment parameters. Table 3.3 integrates the quantification results in Equations (3.3) – (3.10) and summarizes them as the values of *a*, *b* and basic functions assigned to the three different types of CRs as well as the resulting S-CR functions.

Kano Category	a	b	$f(y_i)$	$s_i = af(y_i) + b$
A	$\frac{CS_i - DS_i}{e-1}$	$-\frac{CS_i - eDS_i}{e-1}$	e^{y_i}	$S_i = \frac{CS_i - DS_i}{e-1}e^{y_i} - \frac{CS_i - eDS_i}{e-1}$
O	$CS_i - DS_i$	DS_i	y_i	$S_i = (CS_i - DS_i)y_i + DS_i$
M	$\frac{e(CS_i - DS_i)}{e-1}$	$\frac{eCS_i - DS_i}{e-1}$	$-e^{-y_i}$	$S_i = -\frac{e(CS_i - DS_i)}{e-1}e^{-y_i} + \frac{eCS_i - DS_i}{e-1}$

Table 3.3 S-CR relationship functions for attractive, one-dimensional and must-be attributes

3.4 QFD OPTIMIZATION MODEL

With the information from Stage 1 and Stage 2, the main tasks at Stage 3 are to integrate both qualitative and quantitative results of Kano's model into QFD to develop a QFD optimization model for product design. The detailed process of Stage 3 includes four steps as illustrated in grey rectangles in Figure 3.6. The HOQ is built in Step 1 with inputs from qualitative results of Kano's model in Stage 1. Following that, EC values are normalized for incorporating them into the optimization model. Step 3 concerns integrating Kano's model, particularly quantitative results, into QFD analysis. Finally a QFD optimization model for product design is formulated in Step 4. The basic concept of the QFD optimization model is to translate captured customer needs into ECs with the aim of maximizing customer satisfaction under cost and technical constraints.

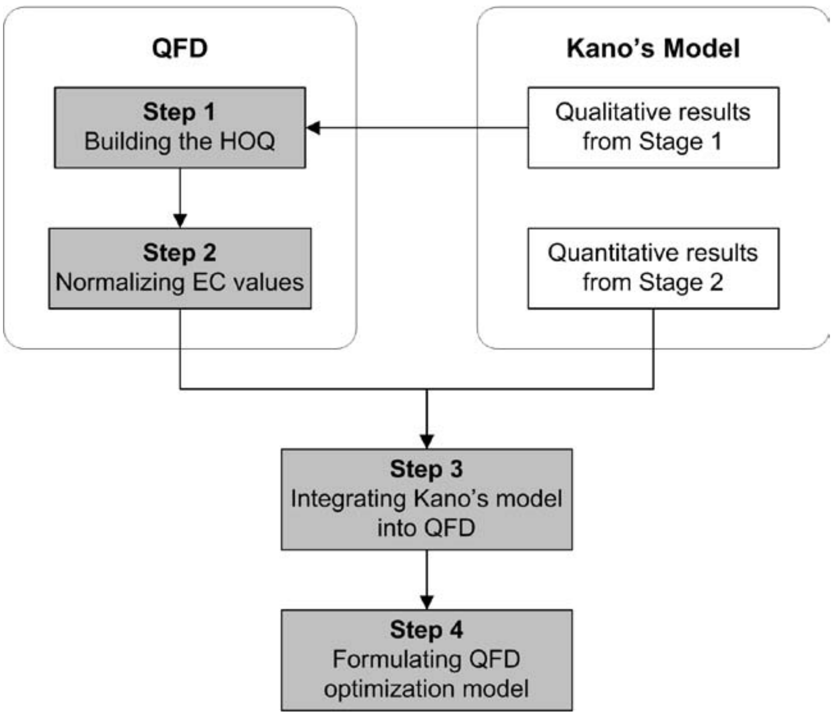

Figure 3.6 Process of Stage 3: QFD optimization model

The notation used in the optimization model including decision variables and parameters is summarized in Table 3.4.

Decision variables	
i	CR index, $i = 1, 2, \ldots\ldots, m$,
j	EC index, $j = 1, 2, \ldots\ldots, n$,
t	competitor index, $t = 1, 2, \ldots\ldots, l$,
k	index of discrete EC values, $k = 1, 2, \ldots\ldots, p$,
x_j	the level of fulfillment for EC j,
$x_{jk} = \begin{cases} 1 \\ 0 \end{cases}$	If value k of EC j is selected for the product design, Otherwise.
y_i	the level of fulfillment for CR i
s_i	the degree of individual customer satisfaction with CR i,
S	overall customer satisfaction with the to-be-designed product

Parameters	
w_i	the importance weighting of CR i,
$Comp_i^t$	the performance weighting of CR i by competitor t,
R_{ij}^{norm}	normalized relationships between CR i and EC j,
c_j	cost of unit improvement for EC j,
d_{kj}	the fulfillment rating related to the discrete value k of EC j ($d_{jk} \neq 0$),
C	total budget for product design,
CS_i	the CS value of CR i
DS_i	the DS value of CR i
KC_i	the Kano category of CR i
ECL_j	the lower boundary of the technical constraints for EC j,
ECH_j	the higher boundary of the technical constraints for EC j,

Table 3.4 Notation

3.4.1 Building the HOQ

Building the HOQ is a critical step in the QFD analysis. During the process of constructing the HOQ, all the important information and data that are relevant to a QFD optimization model will be collected, analyzed and integrated together. Traditionally the HOQ is built to include large amount of information related to customer needs, product design and manufacturing operations. Building the HOQ in an exactly traditional way is time-consuming and ineffectively for the proposed approach, since some of the information collected may not be used in the QFD optimization model that is formulated subsequently. Therefore, in the proposed approach, a customized HOQ is developed to gather relevant information for the QFD optimization model. Six parts of information are collected in sequence and presented in the HOQ as illustrated in Figure 3.7.

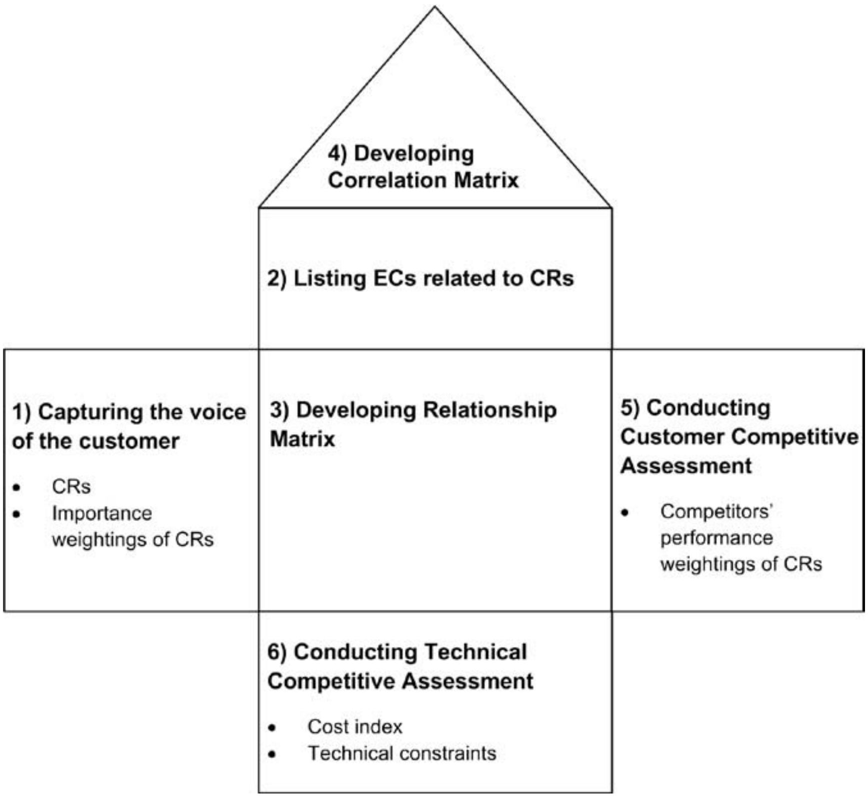

Figure 3.7 Building the customized HOQ

1) Capturing the voice of the customer

The first step in building the HOQ is to generate a list of items representing the voice of the customer. Traditionally this is completed through interviews and surveys. In the proposed approach, CRs can be directly captured from Kano survey results in Stage 1. Indifferent, reverse and questionable attributes are removed from further analysis due to their low impact on customer satisfaction. Only attractive, one-dimensional and must-be attributes are captured into the HOQ.

In addition to identifying CRs for the product concerned, it is also important to determining importance weightings of CRs. In the proposed approach, the importance weightings of CRs are obtained by a self-stated importance questionnaire as shown in Table 3.5, which should be administered at the same time as the Kano questionnaire is given [Fon96]. Customers are required to estimate the importance of all the CRs on a scale from "1 = completely unimportant" to "9 = absolutely important".

How important are the following product attributes?									
Attributes	**Importance**								
	1	2	3	4	5	6	7	8	9
CR 1									
CR 2									
CR 3									

(1 = completely unimportant, 9 = absolutely important)

Table 3.5 Sample questions in a self-stated importance questionnaire

Based on the results of the self-stated importance questionnaire, the importance ratings of CRs can be determined accordingly. Table 3.6 gives an example on the results of a self-stated importance questionnaire with three CRs and ten customer responses. As illustrated in Table 3.6, the importance score of each CR given by each customer is added up to generate a total importance score for each CR. The total importance score of each CR is then divided by the total importance scores of all the CRs to obtain the relative importance rating of each CR as shown in the last row of Table 3.6.

	CR 1	**CR 2**	**CR 3**	**Total**
1	7	6	5	-
2	6	4	8	-
3	2	7	4	-
4	4	3	8	-
5	5	2	5	-
6	9	7	6	
7	6	4	8	
8	4	7	6	
9	7	6	7	
10	5	5	5	
Total	55	51	62	168
Relative Importance (%)	**0.3274** (55/168)	**0.3036** (51/168)	**0.3690** (62/168)	-

Table 3.6 Results of a self-stated importance questionnaire

2) Listing ECs related to CRs

In this part, the product development team identifies and structures ECs that can realize the captured CRs based on their expertise, experience and market research. ECs must be specific and measurable. Therefore, primary ECs can be broken down into one or more ECs at the secondary or tertiary level. The process of refinement and decomposition is continued until every EC on the list is actionable.

3) and 4) Developing relationship matrix and correlation matrix

The relationship between each CRs and ECs and the correlation among ECs are identified in this part. They are measured in a scale of (1, 3, 5, 7, 9) indicating the weakest relationships to the strongest ones. If no relationship between CRs and ECs or dependency among ECs exists, a weighting of 0 is assigned. The correlation of each EC to itself is considered as the strongest relationship with a weighting of 9.

5) and 6) Conducting customer and technical competitive assessment

Traditional HOQ analysis includes a large amount of information in the customer and technical competitive assessment in Part C planning matrix and Part F technical matrix as discussed in Chapter 2. In the proposed approach, the focus is to identify important information that is related to establishing the QFD optimization model. Three main items should be determined in these two steps including competitors' performance weightings of each CR in the planning matrix as well as cost index and technical constraints in the technical matrix.

7) Normalization of the relationship matrix

In order to give a better representation of the relationships between CRs and ECs, the relationship matrix in the HOQ should be normalized before gauging it into the QFD optimization model. Lyman [Lym90] suggested a normalization transformation method on the relationship values contained in a traditional relationship matrix to map the performance of CRs into that of ECs. The normalization transformation method is performed by dividing each of the relationship values in a given row by the row sum of the relationship values. This is represented by Equation (3.11) as follows:

$$r'_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \text{ and } \sum_{j=1}^{n} r'_{ij} = 1 \qquad (3.11)$$

Wasserman [Was93] further extended Lyman's normalization procedure to accommodate dependencies of ECs in the HOQ into the transformation of relationships between CRs and ECs. Therefore, Wasserman's approach is adopted in this step to normalize the relationship matrix in the HOQ.

In Wasserman's approach, the correlation matrix in the HOQ is represented by a series of EC vectors $\{\underline{v}'_k\}$, k = 1, 2, …, n, describing the impact of EC k on other ECs, and the relationships between CRs and ECs is represented as the relationship matrix R_{ij}, as illustrated by Table 3.6.

EC 1 **EC 2** **EC 3** **EC 4** **EC 5**	$\underline{v}'_1$	$\underline{v}'_2$	$\underline{v}'_3$	$\underline{v}'_4$	$\underline{v}'_5$
	EC 1	**EC 2**	**EC 3**	**EC 4**	**EC 5**
CR 1	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}
CR 2	R_{21}	R_{22}	R_{23}	R_{24}	R_{25}
CR 3	R_{31}	R_{32}	R_{33}	R_{34}	R_{35}
CR 4	R_{41}	R_{42}	R_{43}	R_{44}	R_{45}

Table 3.7 Relationship and correlation matrices in the HOQ

The original EC vector $\{\underline{v}'_k\}$ should be converted to the unit vector, $\{v_k\}$, k = 1, 2,…, n, before incorporating it into the normalization procedure to ensure that the square root of the sum of squares of all values in an EC vector equals to 1. To represent dependencies between ECs, the notation, γ_{jk}, is introduced to denote the correlation between EC j and EC k and it is defined as shown in Equation (3.12).

$$\gamma_{jk} \equiv \underline{v}_j \cdot \underline{v}_k (= \cos(\underline{v}_j, \underline{v}_k)) \tag{3.12}$$

The normalization process is then performed as described in Equation (3.13), where R_{ij} denotes the relationship weightings between CR i and EC j in the relationship matrix as shown in Table 3.6. The resulting R_{ij}^{norm} can be interpreted as the incremental change in the level of fulfillment for CR i as EC j achieves a certain fulfillment level. It is noted that the transformation suggested by Wasserman reduces to Lyman's procedure when all the ECs are independent (i.e. $\gamma_{jk} = 1$, if $j = k$, and 0, otherwise).

$$R_{ij}^{norm} = \frac{\sum_{k=1}^{n} R_{ik} \cdot \gamma_{kj}}{\sum_{j=1}^{n}\sum_{k=1}^{n} R_{ij} \cdot \gamma_{jk}}, \quad i = 1,2,\ldots m; j=1,2,\ldots n \tag{3.13}$$

3.4.2 Normalizing EC Values

One drawback in most existing QFD optimization models [Ask00, Fun03, Lai 04] is that they presume EC values to fall into a continuous range and any value in the range could be a possible solution [Lai05]. However, due to technical constraints, certain ECs can only adopt several discrete values instead of a continuous range. For example, the length of a pencil is normally treated as a continuous variable with minimal and maximal feasible values, while the CPU of a computer is considered to be discrete, since only a set of discrete values, such as 2.0 GHz, 2.2GHz and 2.4 GHz, are available for selection. In such a situation, it raises certain difficulties in the traditional QFD optimization model, since the optimal solution obtained may not be practical for product development and manufacturing operations. In order to solve this problem, a special normalization method for the QFD optimization model is developed accordingly. The normalization method assists the optimization model to take into account both discrete and continuous ECs by normalizing their specific technical values into level of fulfillment. Discrete and continuous ECs can be normalized in two different ways as follows.

3.4.2.1 Continuous ECs

EC with continuous values can be further divided into two groups: positive and negative ones. Regarding the positive group, the performance of the EC is positively proportional to its technical value. In other words, the higher the value of the EC, the better the performance is. The negative group of the EC presents just the opposite feature. Its performance is negatively related to its technical value. Take the notebook computer as an example. A typical positive continuous EC of a notebook computer is battery, since it is apparent that the longer hours the battery can last for, the better performance it is. On the contrary, the weight of a notebook computer is a typical negative continuous EC, since generally less weight of a notebook computer represents a better performance.

Positive and negative groups of ECs can be normalized by equation (3.14) and (3.15), respectively. Since they are continuous ECs, a continuous range with maximum and minimum feasible technical values should be identified for each EC. The technical value of each EC is then normalized by considering its fulfillment level during the continuous range.

$$x_j = \frac{X_j^* - X_{\min}}{X_{\max} - X_{\min}} \tag{3.14}$$

$$x_j = \frac{X_{\max} - X_j^*}{X_{\max} - X_{\min}} \tag{3.15}$$

where X^*_j denotes the specific EC technical value, X_{max} and X_{min} represent the maximum and minimum feasible technical values of an EC.

3.4.2.2 Discrete ECs

The normalization process of discrete ECs is handled differently by adding an additional binary variable x_{jk}. For each discrete EC, there is a set of feasible discrete values for selection, each with a fulfillment rating d_{kj} from 0 to 1 indicating a complete unfulfillment to a full fulfillment. The fulfillment rating of each option is determined by the product development team according to their expertise and market research. Generally the best option for a given EC will be assigned a fulfillment rating of 1, while the most basic option of the EC will not be assigned a fulfillment rating of 0, since the most basic option is normally not regarded as a complete unfulfillment. Its fulfillment rating should be determined based on its specific case.

If the discrete value *k of* EC *j* is selected for product design, x_{jk} is then equal to 1, and 0 otherwise. Thus, the level of fulfillment of EC *j* (x_j) is equal to the fulfillment rating of the selected EC options (x_{jk}) as illustrated in Equation (3.16). In doing so, the discrete EC values are mapped into level of fulfillment for building the mathematical programming model. However, one constraint is added to the normalization of discrete ECs as shown in Equation (3.17). The constraint imposes that one and only one discrete EC value is selected for product design among multiple options.

$$x_j = \sum_{k=1}^{p} x_{jk} d_{kj} \text{, for discrete EC } j \tag{3.16}$$

$$\sum_{k=1}^{p} x_{jk} = 1 \text{, for discrete EC } j \tag{3.17}$$

3.4.2.3 Normalization Table

In order to present the normalization information in an organized manner, two tailor-made normalization tables are developed for continuous and discrete ECs, respectively. These two tables are prepared at the very beginning of the normalization process to gather all the relevant technical information of ECs. Once these two normalization tables are ready, the normalization for both discrete and continuous EC can be conducted as discussed previously.

The normalization table for continuous ECs is presented in Table 3.6 with two sample ECs. The table specifies normalization information for each EC including its group (positive or negative), minimum and maximum EC technical values that are feasible.

Continuous ECs	Group	Min EC technical value	Max EC technical value
EC 1	Positive	1 hr	4 hr
EC 2	Negative	2 kg	5 kg

Table 3.8 Normalization table for continuous ECs

Table 3.7 illustrates the format and content of the normalization table for discrete ECs, together with two sample ECs. For each discrete EC, a set of feasible discrete options are listed for selection, each with a fulfillment rating. The number of feasible options for each EC may vary depending on the features of the EC. The product development team is responsible for the decisions on what and how many options are to be included and their corresponding fulfillment ratings. The decisions should be made based on the team's expertise and experience, as well as benchmarking with major competitors in the market.

Discrete ECs	Option 1	Option 2	Option 3	Option 4	Option 5
EC 1	Basic (d_{11}=0.4)	Moderate (d_{12}=0.6)	Advanced (d_{13}=1)	-	-
EC 2	Basic (d_{21}=0.25)	Moderate (d_{22}=0.5)	Advanced I (d_{23}=0.75)	Advanced II (d_{24}=1)	-

Table 3.9 Normalization table for discrete ECs

3.4.3 Integrating Kano's Model into QFD

The first two steps of Stage 3 concentrate on the QFD analysis by building the HOQ and normalization EC values. At Step 3 the focus of the analysis is directed to integrating Kano's model into the QFD optimization model. This step is a central part of the proposed approach, since the results from Kano's model and QFD analysis have eventually been integrated together at this step, which is a major contribution of the proposed approach. The integration process of Kano's model into QFD optimization can be analyzed from two aspects as illustrated in Figure 3.8.

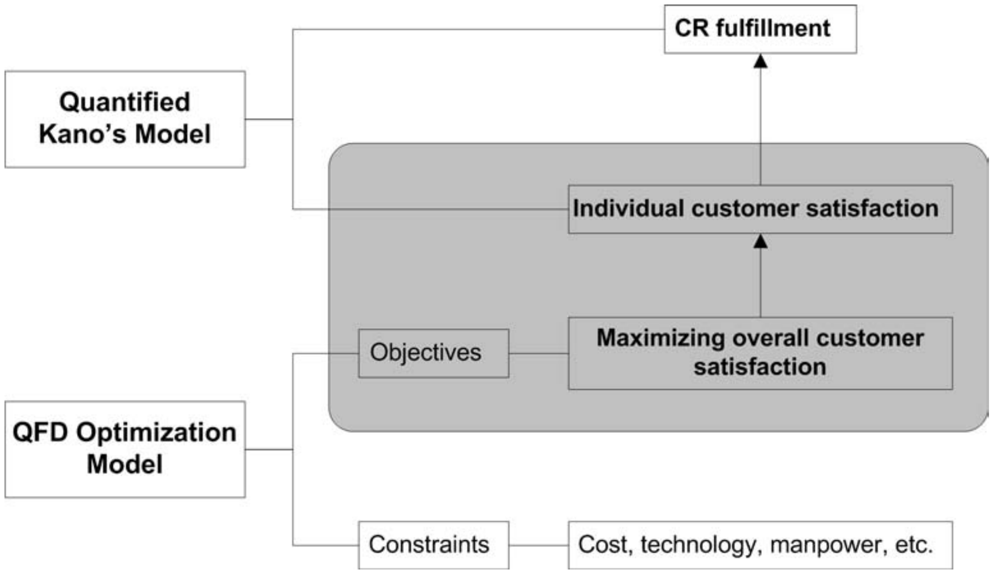

Figure 3.8 Integration of Kano's model into QFD optimization

First, it is noted that the quantitative analysis in Stage 2 has quantified Kano's model by identifying the S-CR relationship functions for three main types of CRs. More specifically, the quantified Kano's model is able to map individual customer satisfaction into CR fulfillment level though the S-CR relationship functions. Second, similar to other mathematical programming, a QFD optimization model mainly consists of two elements: objective functions and constraints. The QFD literature shows that existing QFD optimization models impose different constraints such as cost, technology and manpower depending on the specific problems they intend to solve. However, most of them [Was93, Par98, Ask00, Fun03, Lai05] have a common objective, that is, to maximize customer satisfaction with the to-be-designed product. The common focus of Kano's model and QFD on customer satisfaction suggests that a suitable way to integration is to employ Kano's model to establish the objective function of the QFD optimization model. In doing so, the overall customer satisfaction with the to-be-designed product in the objective function can be decomposed into individual customer satisfaction with each CR, which will be further mapped into the fulfillment level of each CR through quantified Kano's model. Eventually, the CR fulfillment level will be set as a major decision variable in the QFD optimization model.

Based on the above analysis of the integration process, the degree of overall customer satisfaction with the to-be-designed product S (y_1, y_2, ……, y_m) is defined as the weighted sum of the degree of customer satisfaction for individual CRs s_i, as shown in Equation (3.18),

$$S(y_1, y_2, \ldots\ldots, y_m) = \sum_{i=1}^{m} w_i s_i \tag{3.18}$$

where w_i is the relative importance weighting of CR i normalized such that $\sum_{i=1}^{m} w_i = 1$. The relative importance weightings of CRs can be readily retrieved from the HOQ.

The degree of customer satisfaction for individual CRs can be mapped into CR fulfillment level through the S-CR relationship functions in Kano's model as shown in Table 3.3. By integrating S-CR relationship functions in Table 3.3 and Equation (3.18), the objective function of the QFD optimization model is established as Equations (3.19) – (3.22). Overall customer satisfaction is defined as the weighted sum of individual customer satisfaction of CRs as illustrated in Equation (3.19). If the CR is an attractive (A) attribute, S-CR relationship function for attractive attributes Equation (3.20) will be used to determine the individual customer satisfaction of the attractive CR. Similarly, the individual customer satisfaction of one-dimensional and must-be attributes can be obtained by adopting Equation (3.21) and (3.22), respectively.

$$\textbf{MAX} \quad \sum_{i=1}^{m} w_i s_i \tag{3.19}$$

$$s_i = \begin{cases} \dfrac{CS_i - DS_i}{e-1} e^{y_i} - \dfrac{CS_i - eDS_i}{e-1} & (KC_i = A) \quad (3.20) \\[2ex] (CS_i - DS_i) y_i + DS_i & (KC_i = O) \quad (3.21) \\[2ex] -\dfrac{e(CS_i - DS_i)}{e-1} e^{-y_i} + \dfrac{eCS_i - DS_i}{e-1} & (KC_i = M) \quad (3.22) \end{cases}$$

where KC_i denotes the Kano category of CR i, A, O and M represents the three Kano categories: attractive, one-dimensional and must-be, respectively.

3.4.4 Formulating QFD Optimization Model

Once all the above analysis has been completed, the QFD optimization model can be formulated in the final step. The aim of the model is to determine the target values for a set of discrete and continuous ECs with the objective of maximizing overall customer satisfaction with the to-be-designed product subject to technological and economic feasibility. The mathematical model that integrates QFD and Kano's model is formulated as follows:

MAX $\sum_{i=1}^{m} w_i s_i$

$$s_i = \begin{cases} \dfrac{CS_i - DS_i}{e-1} e^{y_i} - \dfrac{CS_i - eDS_i}{e-1} & (KC_i = A) \\ (CS_i - DS_i) y_i + DS_i & (KC_i = O) \\ -\dfrac{e(CS_i - DS_i)}{e-1} e^{-y_i} + \dfrac{eCS_i - DS_i}{e-1} & (KC_i = M) \end{cases}$$

SUBJECT TO

$$y_i = \sum_{j=1}^{n} R_{ij}^{norm} x_j \qquad \forall\, i \qquad (3.23)$$

$$x_j = \sum_{k=1}^{p} x_{jk} d_{kj} \qquad \forall \text{ discrete EC } j \qquad (3.24)$$

$$\sum_{k=1}^{p} x_{jk} = 1 \qquad \forall \text{ discrete EC } j \qquad (3.25)$$

$$\sum_{j=1}^{n} c_j x_j \le C \qquad (3.26)$$

$$y_i \ge \frac{\sum_{t=1}^{l} Comp_i^t}{l} \qquad \forall\, i \qquad (3.27)$$

$$x_j \in [0,1] \qquad \forall\, j \qquad (3.28)$$

$$ECL_j < x_j < ECH_j \qquad (3.29)$$

$$x_{jk} \in \{0,1\} \qquad \forall\, j \qquad (3.30)$$

The objective function of the QFD optimization model represents the overall customer satisfaction with the to-be-designed product, where s_i denotes individual customer satisfactions with different CRs that are obtained through applying different S-CR functions according to their Kano classification.

Equation (3.23) concerns transforming the level of fulfillment of ECs into the level of fulfillment for CRs by multiplying the normalized relationship matrix which is obtained through the relationship matrix in the HOQ and the normalization by Wasserman's approach [Was93]. Equation (3.24) is employed for normalizing technical values of discrete ECs and it defines that the level of fulfillment of discrete EC j (x_j) is equal to the fulfillment rating of the selected EC options (x_{jk}). Equation (3.25) imposes the normalization constraint that one and only one EC option is selected for each discrete EC. Equation (3.26) imposes the budget limit on the product. The sum of costs allocated to each EC for product design should be within the total budget. Equation (3.27) is the constraint of minimum CR fulfillment level demanded by customers for each CR. The minimum fulfillment level of each CR is set to benchmark with the average performance of major competitors in the industry. Equation (3.28) defines the range of x_j from 0 to 1. However, for certain ECs, some technical restrictions may limit the amount of improvement that is possible for them. Therefore, Equation (3.29) specifies the extra boundary conditions for the level of fulfillment of certain ECs. Equation (3.30) defines x_{jk} to be a binary variable.

3.4.5 Solving the Model by GAMS

The model is formulated as a mixed integer non-linear programming model with a non-linear objective function and linear constraints. This type of problem is named as linearly constrained optimization problem which is considerably simplified by having just one non-linear function taking into account, along with a linear programming feasible region [Hil05]. A number of special algorithms have been developed based upon extending the simplex method to consider the non-linear objective function. In this research project, a powerful modeling tool named General Algebraic Modeling System (GAMS) is adopted to solve the non-linear optimization model. GAMS is a high-level modeling system for mathematical programming and optimization. It is specifically designed for modeling linear, nonlinear and mixed integer optimization problems, which is quite suitable for solving the optimization problem in this research project. The structure and basic components of a GAMS model are presented in Table 3.10.

Inputs	Outputs
· **Sets** Declaration Assignment of members · Data (**Parameters, Tables, Scalar**) Declaration Assignment of values · **Variables** Declaration Assignment of type · Assignment of bounds and/or initial values (optional) · **Equations** Declaration Definition · **Model** and **Solve** statements · **Display** statement (optional)	· Echo Print · Reference Maps · Equation Listings · Status Reports · Results

Table 3.10 Basic components of A GAMS model

Sets

`Sets` are the basic building blocks of a GAMS model, corresponding exactly to the indices in the algebraic representation of models.

Data

In a typical GAMS model, data can be entered in three fundamentally different formats including: Lists, Tables and Direct assignments using the statement of **`Parameters`** or **`Table`**.

Variables

The decision variables of a GAMS-expressed model must be declared with a **`Variables`** statement. Each variable is given a name, a domain if appropriate, and optionally text.

Equations

Equations must be declared and defined in separate statements. The format of the declaration is the same as for other GAMS entities. First comes the keyword, **`Equations`** in this case, followed by the name, domain and text of one or more groups of equations or inequalities being declared.

Objective function

It is noted that GAMS has no explicit entity called the 'objective function.' To specify the function to be optimized, GAMS user must create a variable, which is free (unconstrained in sign) or scalar-valued (has no domain) and which appears in an equation definition that equates it to the objective function.

Model and solve statement

The word **model** in GAMS means a collection of equations. Like other GAMS entities, it must be given a name in declaration. The format of the declaration is the keyword **model** followed by the name of the model, followed by a list of equation names enclosed in slashes. If all previously defined equations are to be included, GAMS user can enter **/all/** in place of explicit list.

Once a model has been declared and assigned equations, it is ready to call the solver by a **solve** statement with the format as follows:

- The key word **solve**
- The name of the model to be solved
- The key word **using**
- An available solution procedure. The complete list is

lp for linear programming

nlp for nonlinear programming

mip for mixed integer programming

rmip for relaxed mixed integer programming

minlp for mixed integer nonlinear programming

rminlp for relaxed mixed integer nonlinear programming

mcp for mixed complementarity problems

mpec for mathematical programs with equilibrium constraints

cns for constrained nonlinear systems

The key components of a GAMS model have been described briefly as above. More detailed information about the GAMS program can be found in its user manual and website (http://www.gams.com/).

3.5 SUMMARY

In this chapter, a novel approach to integrating Kano's model into QFD optimization is proposed to optimize product design with the objective of maximizing customer satisfaction under various cost and technical constraints. The integrative approach is developed to address the problems of three areas in the literature of QFD and Kano's model which are discussed in Chapter 1 and 2, including quantification of Kano's model, robust integration of Kano's model into QFD and methodological problems in the QFD optimization model.

The proposed integrative approach consists of three stages including applying traditional Kano's model, conducting quantitative analysis of Kano's model and formulating the QFD optimization model.

The integrative approach starts with conducting traditional Kano's model in Stage 1. This stage first discusses the preparation of customer survey to capture important customer data by adopting a Kano questionnaire format. Customer data collected back is then analyzed by the traditional Kano's model to determine the Kano category as well as CS and DS values for each CR.

Based on the survey results from Stage 1, quantitative analysis of Kano's model is then conducted in Stage 2 to quantify the relationships between CR fulfillment and customer satisfaction for three different Kano categories of CRs by the following four steps: calculating CS and DS values, determining CS and DS points, plotting the S-CR relationship curves and identifying S-CR relationship functions.

The quantitative results from Kano's model are then transferred into Stage 3 for proper integration with QFD and formulation of a QFD optimization model. The final results demonstrate the optimal product design that maximizes customer satisfaction under various constraints. Not only has the fulfillment level been determined for each EC, but also specific EC technical value corresponding to the fulfillment level of each CR is identified. CR fulfillment and customer satisfaction level have also been calculated to demonstrate how the optimal design performs from the point of customers' view.

In order to demonstrate the application of the proposed integrative approach, a case study of the notebook computer design is presented in the next chapter. The proposed integrative approach is adopted to seek an optimal notebook computer design so as to maximize customer satisfaction under various constraints.

CHAPTER 4

CASE STUDY

4.1 INTRODUCTION

It is generally accepted that the personal computer (PC) era began with IBM's introduction of its first PC system in 1981 [Bae98]. Since the PC was introduced, fast-growing customer demand and intense competition among PC manufacturers have made the PC technologies advance at a dramatic pace. The continuous development of high performance microprocessor, large capacity of storage device, high quality display technology has greatly improved the PC design to satisfy the ever-changing needs and requirements of customers. Moreover, many new functions, such as video, sound, networking, have been added to the PC systems. The extended functions of PCs have resulted in various new applications and new categories of PCs, such as portable PC or mobile PC, multimedia PC and network computer. Among these new categories of PCs, the battery-powered mobile PC, also called the notebook computer is probably the most dynamic and fast-growing segment in the PC market since its introduction in 1989. It was reported that in 1990 the notebook computer accounted for 12 % of PCs and increased to 17.3 % of the total PC unit shipment in 1996 [Com97]. Currently, customers begin to express their new ideas and requirements for a notebook computer, that is, high performance and multi-functionality as a desktop PC with attractive appearance and high mobility in terms of size, weight and exterior design.

The development of PCs demonstrates that the PC market has developed so rapidly with ever-changing technologies and dynamic customer needs. Optimizing PC design to meet customer needs while maintain market competitiveness becomes a major challenge for PC manufacturers. Therefore, the problem of PC design is selected for investigation in this research project. Since the PC market is so diversified with various products and segments, the focus of this case study rests on how to improve the design of a notebook computer. Target customers are university students who are a major customer segment in the notebook computer market. As the production of PCs in the company mainly involves the assembly of different components, the discussion of notebook computer design therefore is focused on the component level, that is, hardware configuration of a notebook computer.

4.2 IMPLEMENTATION OF THE CASE STUDY

The proposed integrative approach developed in Chapter 3 is adopted in the case study to demonstrate its application in customer-focused product design. The primary objective is to optimize the notebook computer design so as to maximize customer satisfaction of university students under constraints. The case study of a notebook computer design is conducted by the following eight steps.

Step 1 ***Kano Customer Survey***

Prepare the Kano questionnaire and survey target customers.

Step 2 ***Kano Survey Analysis***

Process the questionnaire results by traditional Kano's model to determine the Kano category as well as CS and DS values for each CR.

Step 3 ***Kano Quantitative Analysis***

Identify the S-CR relationship functions for each CR by the proposed Kano quantitative analysis.

Step 4 ***Construction of the HOQ***

Build the HOQ of a notebook computer to collect all the relevant information for the QFD optimization model.

Step 5 ***Normalization of EC values***

Normalize both discrete and continuous ECs to transfer specific EC technical values into levels of fulfillment of ECs.

Step 6 ***Integration of Kano's Model into QFD Optimization***

Integrate all the information including qualitative and quantitative results from Kano's model, the HOQ and EC normalization information to formulate the QFD optimization model for optimal design of a notebook computer

Step 7 ***Solving the Model by GAMS***

The QFD optimization model of the case study is compiled into a GAMS programme and solved by the GAMS solver of MINLP (mixed integer non-linear programming).

Step 8 ***Results and Discussions***

Results of the case study are obtained from the GAMS solution. Through the results, the improvements of the proposed approach compared with the traditional product design method are discussed in detail.

4.2.1 Kano Customer Survey

The case study starts with conducting Kano customer survey in Step 1 to capture customer data about the notebook computer design by adopting a Kano questionnaire format. This step consists of three main tasks including collecting primary customer data through the preliminary study, developing the Kano questionnaire of the notebook computer, and surveying target customers.

A customer survey questionnaire should include meaningful questions that can capture valuable customer expectations for a successful product [Kot00]. Expertise and user inputs are essential to ensure that the questionnaire offers reasonable questions to customers and provides valid and accurate data for survey analysis. Consistent with this thought, the CR options presented in the Kano questionnaires are based on a preliminary study that identifies general needs of undergraduate students for notebook computers.

The preliminary study is a combination of focus group interview of target customers and market research through information searching on the internet as well as previous market surveys results. Based on the preliminary study, a list of CR options is generated. They are further refined and divided into three groups, namely appearance, performance and function, as shown in Table 4.1. Accordingly, the Kano questionnaire is developed to examine these three groups of CRs.

NOTEBOOK COMPUTER SYSTEM	
Primary CRs	**Secondary CRs**
Appearance	Stylish design Light and mobile Large screen size
Performance	High computing speed Solid audio capabilities Powerful graphics solution Large storage High network performance
Function	Multimedia function Expandable device Wireless LAN Remote control

Table 4.1 Primary and secondary CRs of a notebook computer

Based on the preliminary study, the Kano questionnaire is developed and organized into three sections including notebook computer usage, functional and dysfunctional sections. The first section of the questionnaire concerns the primary PC usage of the participant. The purpose of this question is to divide the target notebook computer user group (university students) into subgroups based on their prime usage of a PC, since PC usage may affect customers' expectation to the fulfillment of certain CRs. However, this research project on the notebook computer design intends to fulfill the general requirements of the target customers. Further research and investigation can be conducted to have different PC designs for different group of users based on their PC usage.

The functional and dysfunctional sections of the questionnaire concerns customers' response about including (functional) or omitting (dysfunctional) a CR, which follows the standard format of the Kano questionnaire. Each section discusses in detail three groups of CRs, each with its second-level specific requirements which were identified in the preliminary study as shown in Table 4.1. Participants are required to express their feelings of whether they like, need, are neutral about, could live with or dislike in both functional and dysfunctional conditions of a CR. Figure 4.1 and 4.2 show some functional and dysfunctional questions in the Kano questionnaire. The detailed questionnaire is shown in Appendix I. The Kano questionnaire was then distributed to undergraduate students from different years of study and various disciplines including engineering, business, construction and land use, hotel and tourism management, etc.

It is noted that another questionnaire named the self-stated importance questionnaire of the notebook computer design, as shown in Table 4.2, is also administered at the same time as the Kano questionnaire is given to target customers. In this questionnaire, customers are required to estimate the importance of all the three groups of CRs of a notebook computer on a scale from "1 = completely unimportant" to "9 = absolutely important". The results of the questionnaire is used to determine the importance weightings of CRs as listed in the HOQ which will discussed in Step 4.

SECTION 2: FUNCTIONAL FORM

Consider each attribute one at a time and how you would feel if it was included. Please check only one out of the following five choices for each row.

1 = I like this feature included.
2 = This feature must be included.
3 = I am neutral about this feature.
4 = I can live with including this feature.
5 = I dislike including this feature.

	1	2	3	4	5
APPEARANCE					
Light and mobile	O	O	O	O	O
Stylish design	O	O	O	O	O
Large screen size	O	O	O	O	O

Figure 4.1 Functional form questions in the Kano questionnaire

SECTION 3: DYSFUNCTIONAL FORM

The same attributes mentioned in Section 2 could be omitted from the notebook computer system. Consider each attribute one at a time and how you would feel if it was not included (omitted). Please check only one out of the following five choices for each row.

1 = I like this feature omitted.
2 = This feature must be omitted.
3 = I am neutral about this feature.
4 = I can live with omitting this feature.
5 = I dislike omitting this feature.

	1	2	3	4	5
APPEARANCE					
Light and mobile	O	O	O	O	O
Stylish design	O	O	O	O	O
Large screen size	O	O	O	O	O

Figure 4.2 Dysfunctional form questions in the Kano questionnaire

How important are the following product attributes? (Please check the importance of each CR, 1 = completely unimportant, 9 = absolutely important)									
Attributes	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Appearance									
Stylish design	O	O	O	O	O	O	O	O	O
Light and mobile	O	O	O	O	O	O	O	O	O
Large screen size	O	O	O	O	O	O	O	O	O
Performance									
High computing speed	O	O	O	O	O	O	O	O	O
Powerful graphics solution	O	O	O	O	O	O	O	O	O
Solid audio capability	O	O	O	O	O	O	O	O	O
Large storage	O	O	O	O	O	O	O	O	O
High network performance	O	O	O	O	O	O	O	O	O
Function									
Multimedia function	O	O	O	O	O	O	O	O	O
Expandable device	O	O	O	O	O	O	O	O	O
Wireless LAN	O	O	O	O	O	O	O	O	O
Remote control	O	O	O	O	O	O	O	O	O

Table 4.2 Self-stated importance questionnaire of the notebook computer design

4.2.2 Kano Survey Analysis

The Kano customer survey received 125 responses in total that represent an undergraduate student community characterized by various disciplines and years of study. The questionnaires that have been collected back are then processed by the traditional analysis in Kano’s model to determine the Kano category as well as CS and DS values for each CR as discussed in the previous section. The number of customer responses in each Kano category for each CR is summarized in Table 4.2. The final Kano classification for each CR is determined by the most frequent response method where one of the six categories with the highest tally indicates the dominant customer view for that CR. According to classification results, three attributes, large screen size, high network performance and remote control, are classified as indifferent attributes. Therefore, they would not be included into the further analysis due to their little impact on customer satisfaction.

In addition to the classification results, CS and DS values for each CR are calculated accordingly. It can be seen that must-be and attractive attributes have a comparatively higher value (> 0.5) of either CS or DS indicating their great impact on only one side of customer satisfaction scale in the Kano diagram. One-dimensional attributes tend to have higher values of both CS and DS suggesting their linear impact on customer satisfaction. Indifferent attributes obtain low values of both CS and DS which is an indication of their lower impact on customer satisfaction. These observations of CS and DS values are consistent with the Kano classification in the Kano diagram discussed previously.

CRs	A	O	M	I	R	Q	Total	Kano Type	CS	DS
Appearance										
Stylish design	**70**	25	14	15	0	1	125	**A**	0.7661	-0.3145
Light and mobile	15	**75**	27	7	1	0	125	**O**	0.7258	-0.8226
Large screen size	20	15	11	**72**	5	2	125	**I**	0.2966	-0.2203
Performance										
High computing speed	24	**64**	23	11	2	1	125	**O**	0.7213	-0.7131
Powerful graphics solution	**69**	31	15	9	1	0	125	**A**	0.8065	-0.3710
Solid audio capability	**76**	25	12	10	2	0	125	**A**	0.8211	-0.3008
Large storage	24	20	**70**	11	2	0	125	**M**	0.3577	-0.7317
High network performance	16	37	22	**47**	1	2	125	**I**	0.4344	-0.4836
Function										
Multimedia function	28	**60**	21	13	1	2	125	**O**	0.7213	-0.6639
Expandable device	**65**	18	16	25	0	1	125	**A**	0.6694	-0.2742
Wireless LAN	14	19	**81**	10	0	1	125	**M**	0.2661	-0.8065
Remote control	23	5	11	**83**	2	1	125	**I**	0.2295	-0.1311

Table 4.3 Kano survey results

4.2.3 Kano Quantitative Analysis

Based on the results of survey analysis from Step 2, the proposed Kano quantitative analysis is applied in Step 3 to derive quantitative information about customer needs of a notebook computer. Indifferent attributes have been removed from the table and the remaining CRs are numbered from 1 to 9. Since CS and DS values have already been calculated, CS and DS points for each CR can be easily determined as illustrated in Table 4.3. Meanwhile, suitable equations in Table 3.3 are selected to calculate the values of *a*, *b* and to determine the basic function for each CR according to its Kano category. In this way, all the S-CR relationship functions are obtained in the last column of Table 4.4. Moreover, the S-CR relationship curves of attractive, one-dimensional and must-be attributes are plotted in Figures 4.3 – 4.5, respectively.

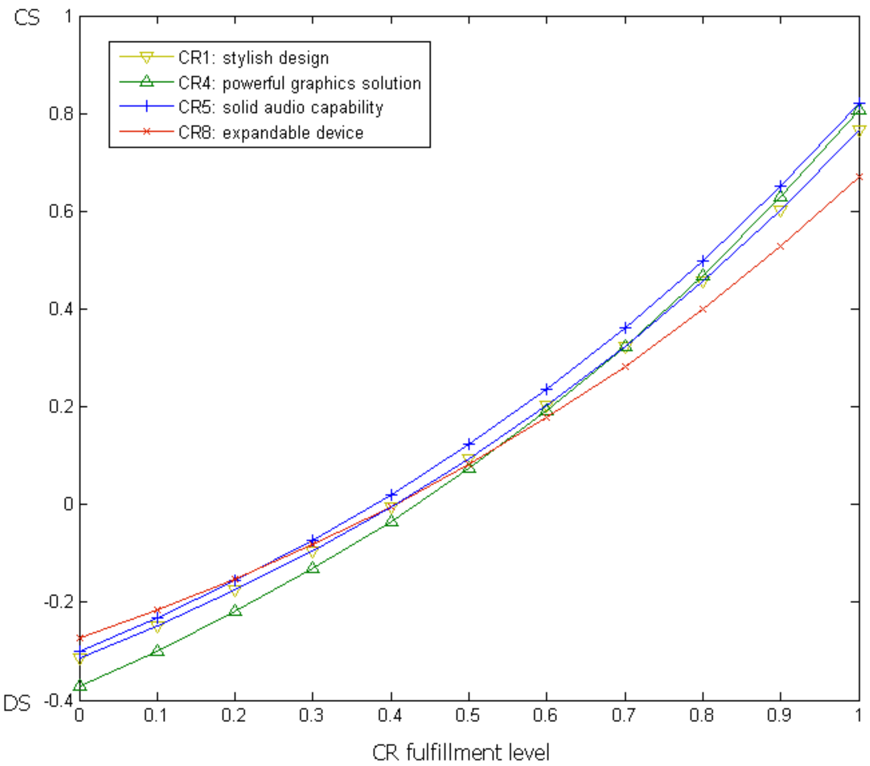

Figure 4.3 Refined S-CR relationship curves for attractive attributes

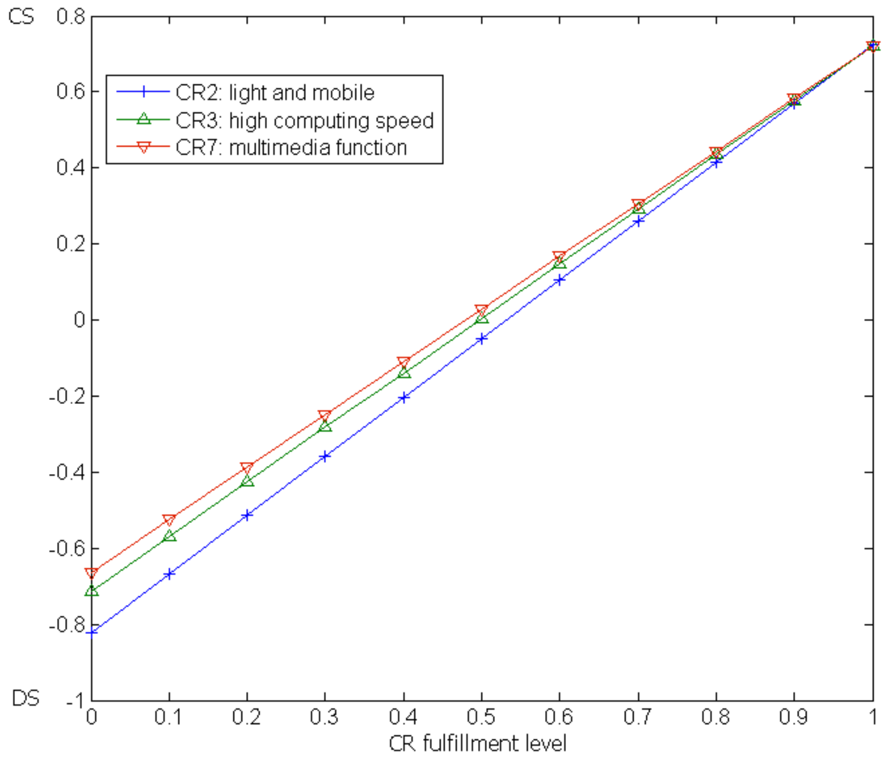

Figure 4.4 Refined S-CR relationship curves for one-dimensional attributes

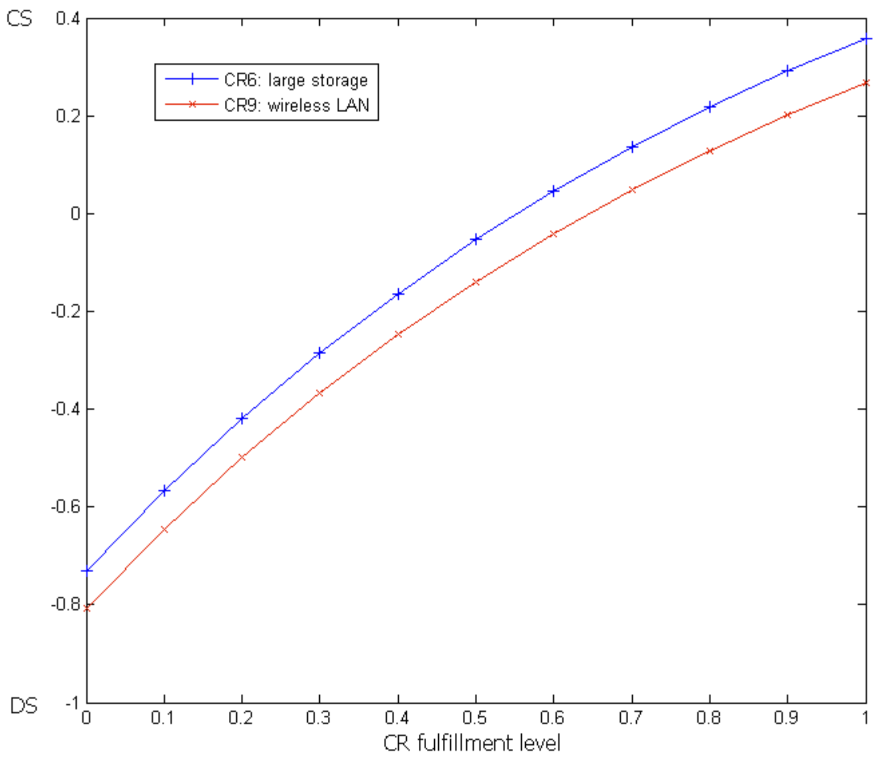

Figure 4.5 Refined S-CR relationship curves for must-be attributes

CRs	Kano Type	CS	DS	*a*	*b*	$f(y)$	$s_i = af(y) + b$
Appearance							
1. Stylish design	**A**	(1, 0.7661)	(0, -0.3145)	0.6289	-0.9434	e^y	$s = 0.6289e^y - 0.9434$
2. Light and mobile	**O**	(1, 0.7258)	(0, -0.8226)	1.5484	-0.8226	y	$s = 1.5484y - 0.8226$
Performance							
3. High computing speed	**O**	(1, 0.7213)	(0, -0.7131)	1.4344	-0.7131	y	$s = 1.4344y - 0.7131$
4. Powerful graphics solution	**A**	(1, 0.8065)	(0, -0.3710)	0.6852	-1.0562	e^y	$s = 0.6852e^y - 1.0562$
5. Solid audio capability	**A**	(1, 0.8211)	(0, -0.3008)	0.6529	-0.9538	e^y	$s = 0.6529e^y - 0.9538$
6. Large storage	**M**	(1, 0.3577)	(0, -0.7317)	1.7235	0.9917	$-e^{-y}$	$s = -1.7235e^{-y} + 0.9917$
Function							
7. Multimedia function	**O**	(1, 0.7213)	(0, -0.6639)	1.3852	-0.6639	y	$s = 1.3852y - 0.6639$
8. Expandable device	**A**	(1, 0.6694)	(0, -0.2742)	0.5491	-0.8233	e^y	$s = 0.5491e^y - 0.8233$
9. Wireless LAN	**M**	(1, 0.2661)	(0, -0.8065)	1.6968	0.8903	$-e^{-y}$	$s = -1.6968e^{-y} + 0.8903$

Table 4.4 S-CR relationship functions for CRs

4.2.4 Construction of the HOQ

Following the Kano quantitative analysis in Step 3, the next step is to build the HOQ of a notebook computer to collect all the relevant information for formulating the QFD optimization model.

The HOQ of the notebook computer design is constructed as illustrated in Figure 4.4. The CRs listed in the HOQ are extracted directly from Kano survey results in Step 2 with their corresponding relative importance weightings obtained through a self-stated importance questionnaire administered in Step 1. The detailed results of the self-stated importance questionnaire are illustrated in Appendix II. Since the PC design in this study refers to the hardware configuration of a notebook computer, the ECs listed in the HOQ are the most common technical specifications of customers' concern, such as CPU, RAM, hard drive and LCD display. The relationships between CRs and ECs together with the correlations among ECs are measured in a scale of (1, 3, 5, 7, 9) indicating the weakest relationships to the strongest ones. If no relationship or dependency exists, a weighting of 0 is assigned, that is, the box is left blank. The correlation of each EC to itself is considered as the strongest relationship with a weight of 9. Benchmarking information is provided at the right-hand side of the HOQ illustrating competitors' performance ratings of each CR. In this case study, four competitors are included for benchmarking. Cost index, which is the cost of unit improvement for each EC, is specified at the base of the HOQ. Technical constraints are identified for those ECs that have either a lower or a higher limit of their technical values.

1. CPU	9	3	5	7	0	0	0	3	0
2. RAM	3	9	7	5	3	0	3	3	0
3. Hard disk	5	7	9	0	0	0	0	3	1
4. Graphic card	7	5	0	9	7	0	1	3	0
5. Wireless network card	0	3	0	7	9	0	0	3	0
6. LCD display	0	0	0	0	0	9	0	1	3
7. Optical drive	0	3	0	1	0	0	9	1	5
8. Battery	3	3	3	3	3	1	1	9	7
9.Weight	0	0	3	0	0	5	5	7	9

CRs	ECs	Relative Importance (%)	1. CPU	2. RAM	3. Hard disk	4. Graphic card	5. Wireless network card	6. LCD display	7. Optical drive	8. Battery	9.Weight	Comp^1	Comp^2	Comp^3	Comp^4
Appearance	1. Stylish design	9.49	0	0	0	0	0	9	5	7	7	0.85	0.74	0.70	0.76
	2. Light and mobile	10.94	5	0	1	0	3	9	7	5	9	0.60	0.71	0.45	0.60
Performance	3. High computing speed	12.07	9	9	9	7	0	0	3	5	0	0.72	0.55	0.40	0.47
	4. Powerful graphics solution	11.39	5	7	3	9	0	9	0	1	0	0.90	0.84	0.75	0.71
	5. Solid audio capability	11.78	7	7	3	0	0	0	5	1	0	0.54	0.55	0.61	0.60
	6. Large storage	11.42	0	3	9	0	0	0	5	0	0	0.83	0.75	0.50	0.66
Function	7. Multimedia function	11.94	7	7	5	9	1	9	7	3	0	0.68	0.60	0.57	0.60
	8. Expandable device	10.10	0	0	0	0	0	0	5	7	5	0.75	0.72	0.65	0.69
	9. Wireless LAN	10.88	0	0	0	0	9	0	0	0	0	0.79	0.62	0.87	0.75
Cost Index (in hundred dollars)			19.5	17.5	14	16	13	16	15	12	11				
Technical Constraints (ECL)			0.7	-	-	-	-	0.65	-	-	0.7				
Technical Constraints (ECH)			-	-	0.85	0.80	-	-	-	-	-				

Table 4.5 The HOQ of the notebook computer design

The relationship matrix **R**, which locates in the inner hall of the above HOQ should be normalized by applying Wasserman's approach (1993) before gauging it into the QFD optimization model. As described in Chapter 3, Wasserman's normalization approach starts with converting the original correlation matrix in the roof of the HOQ to unit vectors $\{\underline{v}_k\}$, $k = 1, 2, \ldots, 9$ as follows.

$\underline{v}_1$ = [0.6843 0.2281 0.3801 0.5322 0 0 0 0.2281 0]^T

$\underline{v}_2$ = [0.2171 0.6512 0.5065 0.3618 0.2171 0 0.2171 0.2171 0]^T

$\underline{v}_3$ = [0.3892 0.5449 0.7006 0 0 0 0 0.2335 0.0778]^T

$\underline{v}_4$ = [0.4785 0.3418 0 0.6152 0.4785 0 0.0684 0.2051 0]^T

$\underline{v}_5$ = [0 0.2466 0 0.5754 0.7398 0 0 0.2466 0]^T

$\underline{v}_6$ = [0 0 0 0 0 0.9435 0 0.1048 0.3145]^T

$\underline{v}_7$ = [0 0.2774 0 0 0 0 0.8321 0.0925 0.4623]^T

$\underline{v}_8$ = [0.2255 0.2255 0.2255 0 0.2255 0.0752 0.0752 0.6765 0.5262]^T

$\underline{v}_9$ = [0 0 0.2182 0 0 0.3637 0.3637 0.5092 0.6547]^T

To model the dependencies between EC *j* and EC *k*, γ_{jk} is calculated by the dot product of vectors $\underline{v}_j$ and $\underline{v}_k$. The results of γ_{jk} are illustrated in the matrix **M**. Finally, the normalized relationships between CR *i* and EC *j*, is calculated by incorporating matrices **M** and **R** into Equation (3.13) and the results are obtained in the matrix $\mathbf{R}^{\mathbf{norm}}$.

$$\mathbf{M} = \begin{bmatrix} 1.0000 & 0.7317 & 0.7103 & 0.7796 & 0.4187 & 0.0239 & 0.1335 & 0.5658 & 0.1991 \\ 0.7317 & 1.0000 & 0.8450 & 0.7123 & 0.5829 & 0.0228 & 0.4147 & 0.6037 & 0.3000 \\ 0.7103 & 0.8450 & 1.0000 & 0.4204 & 0.1920 & 0.0490 & 0.2087 & 0.5676 & 0.3228 \\ 0.7796 & 0.7123 & 0.4204 & 1.0000 & 0.8429 & 0.0215 & 0.2275 & 0.5755 & 0.1293 \\ 0.4187 & 0.5829 & 0.1920 & 0.8429 & 1.0000 & 0.0259 & 0.1444 & 0.5190 & 0.1256 \\ 0.0239 & 0.0228 & 0.0490 & 0.0215 & 0.0259 & 1.0000 & 0.1551 & 0.3073 & 0.6024 \\ 0.1335 & 0.4147 & 0.2087 & 0.2275 & 0.1444 & 0.1551 & 1.0000 & 0.4517 & 0.6523 \\ 0.5658 & 0.6037 & 0.5676 & 0.5755 & 0.5190 & 0.3073 & 0.4517 & 1.0000 & 0.7928 \\ 0.1991 & 0.3000 & 0.3228 & 0.1293 & 0.1256 & 0.6024 & 0.6523 & 0.7928 & 1.0000 \end{bmatrix}$$

$$\mathbf{R} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 9 & 5 & 7 & 7 \\ 5 & 0 & 1 & 0 & 3 & 9 & 7 & 5 & 9 \\ 9 & 9 & 9 & 7 & 0 & 0 & 3 & 5 & 0 \\ 5 & 7 & 3 & 9 & 0 & 9 & 0 & 1 & 0 \\ 7 & 7 & 3 & 0 & 0 & 0 & 5 & 1 & 0 \\ 0 & 3 & 9 & 0 & 0 & 0 & 5 & 0 & 0 \\ 7 & 7 & 5 & 9 & 1 & 9 & 7 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 5 & 7 & 5 \\ 0 & 0 & 0 & 0 & 9 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\mathbf{R}^{\mathbf{norm}} = \begin{bmatrix} 0.0603 & 0.0832 & 0.0747 & 0.0606 & 0.0529 & 0.1562 & 0.1366 & 0.1700 & 0.2054 \\ 0.0871 & 0.1031 & 0.0873 & 0.0866 & 0.0701 & 0.1182 & 0.1219 & 0.1573 & 0.1685 \\ 0.1558 & 0.1648 & 0.1494 & 0.1411 & 0.0999 & 0.0153 & 0.0694 & 0.1322 & 0.0722 \\ 0.1433 & 0.1459 & 0.1234 & 0.1424 & 0.1079 & 0.0710 & 0.0578 & 0.1266 & 0.0818 \\ 0.1493 & 0.1672 & 0.1494 & 0.1294 & 0.0851 & 0.0150 & 0.0956 & 0.1268 & 0.0821 \\ 0.1296 & 0.1775 & 0.1761 & 0.0988 & 0.0588 & 0.0180 & 0.1137 & 0.1285 & 0.0989 \\ 0.1324 & 0.1442 & 0.1197 & 0.1322 & 0.0988 & 0.0602 & 0.0858 & 0.1309 & 0.0957 \\ 0.0747 & 0.1037 & 0.0881 & 0.0772 & 0.0662 & 0.0789 & 0.1518 & 0.1757 & 0.1835 \\ 0.1087 & 0.1513 & 0.0498 & 0.2189 & 0.2597 & 0.0067 & 0.0375 & 0.1348 & 0.0326 \end{bmatrix}$$

4.2.5 Normalization of EC Values

In Step 5 both discrete and continuous ECs are normalized to convert their specific technical value to level of fulfillment for ECs. The normalization information for both discrete and continuous ECs is provided in Table 4.5. Most ECs such as CPU, RAM and hard drive are classified as discrete ones with several feasible options. The fulfillment rating is determined in accordance with the specific technical value in each option. Based on the above mentioned information, discrete ECs can be normalized by Equations (3.16) and (3.17). Only two continuous ECs, battery and weight, are identified in this case study. According to their group classification, positive or negative, Equations (3.14) or (3.15) are applied to normalize their EC values.

Discrete ECs	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 1**
1. CPU	1.66GHz (d_{11}=0.4)	2.1GHz (d_{12}=0.6)	2.2GHz (d_{13}=0.8)	2.4GHz (d_{14}=1)	
2. RAM	256MB (d_{21}=0.25)	512MB(d_{22}=0.5)	1GB (d_{23}=0.75)	2GB (d_{24}=1)	
3. Hard disk	80G (d_{31}=0.2)	120G (d_{32}=0.4)	160G (d_{33}=0.6)	250G (d_{34}=0.85)	320G (d_{35}=1)
4. Graphic card	Integrated (d_{41}=0.4)	128MB (d_{42}=0.6)	256MB (d_{43}=0.8)	Dual (2*256MB) (d_{44}=1)	
5. Wireless network card	Basic (d_{51}=0.6)	Advanced I (d_{52}=0.9)	Advanced II (d_{53}=1)		
6. LCD display	11.1" (d_{61}=0.2)	12.2" (d_{62}=0.4)	13.1" (d_{63}=0.6)	15.1" (d_{64}=0.8)	17.1" (d_{65}=1)
7. Optical drive	DVD/CD-RW*Combo Drive (d_{71}=0.7)	8X DVD*+/-RW Drive (d_{72}=1)			
Continuous ECs	Group	**Min EC technical value**		**Max EC technical value**	
8. Battery	Positive	1 hr		4 hr	
9. Weight	Negative	1.5 Kg		3.5 Kg	

Table 4.6 Normalization of ECs

4.2.6 Integration of Kano's Model into QFD Optimization

At Step 6 which is the most important step of the whole approach, the QFD optimization model for the notebook computer design is formulated to determine optimal values for a set of ECs by integrating all the information gathered from previous steps including qualitative and quantitative results from Kano's model, the HOQ and EC normalization information.

MAX

$$S = 0.0949s_1 + 0.1094s_2 + 0.1207s_3 + 0.1139s_4 + 0.1178s_5 + 0.1142s_6 + 0.1194s_7 + 0.1010s_8 + 0.1088s_9$$

$$s_1 = 0.6289e^{y_1} - 0.9434$$

$$s_2 = 1.5484y_2 - 0.8226$$

$$s_3 = 1.4344y_3 - 0.7131$$

$$s_4 = 0.6852e^{y_4} - 1.0562$$

$$s_5 = 0.6529e^{y_5} - 0.9538$$

$$s_6 = -1.7235e^{-y_6} + 0.9917$$

$$s_7 = 1.3852y - 0.6639$$

$$s_8 = 0.5491e^{y_8} - 0.8233$$

$$s_9 = -1.6968e^{-y_9} + 0.8903$$

SUBJECT TO

$$y_1 = 0.0603x_1 + 0.0832x_2 + 0.0747x_3 + 0.0606x_4 + 0.0529x_5 + 0.1562x_6 + 0.1366x_7 + 0.1700x_8 + 0.2054x_9$$

$$y_2 = 0.0871x_1 + 0.1031x_2 + 0.0873x_3 + 0.0866x_4 + 0.0701x_5 + 0.1182\,x_6 + 0.1219x_7 + 0.157300x_8 + 0.1685x_9$$

$$y_3 = 0.1558x_1 + 0.1648x_2 + 0.1494x_3 + 0.1411x_4 + 0.0999x_5 + 0.0153\,x_6 + 0.0694x_7 + 0.1322x_8 + 0.0722x_9$$

$$y_4 = 0.1433x_1 + 0.1459x_2 + 0.1234x_3 + 0.1424x_4 + 0.1079x_5 + 0.0710x_6 + 0.0578x_7 + 0.1266x_8 + 0.0818x_9$$

$$y_5 = 0.1493x_1 + 0.1672x_2 + 0.1494x_3 + 0.1294x_4 + 0.0851x_5 + 0.0150x_6 + 0.0956x_7 + 0.1268x_8 + 0.0821x_9$$

$$y_6 = 0.1296x_1 + 0.1775x_2 + 0.1761x_3 + 0.0988x_4 + 0.0588x_5 + 0.0180x_6 + 0.1137x_7 + 0.1285x_8 + 0.0989x_9$$

$$y_7 = 0.1324x_1 + 0.1442x_2 + 0.1197x_3 + 0.1322x_4 + 0.0988x_5 + 0.0602x_6 + 0.0858x_7 + 0.1309x_8 + 0.0957x_9$$

$$y_8 = 0.0747x_1 + 0.1037x_2 + 0.0881x_3 + 0.0772x_4 + 0.0662x_5 + 0.0789x_6 + 0.1518x_7 + 0.1757x_8 + 0.1835x_9$$

$$y_9 = 0.1087x_1 + 0.1513x_2 + 0.0498x_3 + 0.2189x_4 + 0.2597x_5 + 0.0067x_6 + 0.0375x_7 + 0.1348x_8 + 0.0326x_9$$

$$19.5x_1 + 17.5x_2 + 14x_3 + 16x_4 + 13x_5 + 16x_6 + 15x_7 + 12x_8 + 11x_9 \le 120$$

$$x_1 = 0.25x_{11} + 0.5x_{12} + 0.8x_{13} + x_{14}$$

$$x_2 = 0.25x_{21} + 0.5x_{22} + 0.75x_{23} + x_{24}$$

$$x_3 = 0.2x_{31} + 0.4x_{32} + 0.6x_{33} + 0.8x_{34} + x_{35}$$

$$x_4 = 0.25x_{41} + 0.5x_{42} + 0.75x_{43} + x_{44}$$

$$x_5 = 0.33x_{51} + 0.66x_{52} + x_{53}$$

$$x_6 = 0.2x_{61} + 0.4x_{62} + 0.6x_{63} + 0.8x_{64} + x_{65}$$

$$x_7 = 0.6x_{71} + x_{72}$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 1$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1$$

$$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} = 1$$

$$x_{41} + x_{42} + x_{43} + x_{44} = 1$$

$$x_{51} + x_{52} + x_{53} = 1$$

$$x_{61} + x_{62} + x_{63} + x_{64} + x_{65} = 1$$

$$x_{71} + x_{72} = 1$$

$$y_1 \geq \frac{0.85 + 0.74 + 0.70 + 0.76}{4}$$

$$y_2 \geq \frac{0.6 + 0.71 + 0.45 + 0.6}{4}$$

$$y_3 \geq \frac{0.72 + 0.55 + 0.4 + 0.47}{4}$$

$$y_4 \geq \frac{0.9 + 0.84 + 0.75 + 0.71}{4}$$

$$y_5 \geq \frac{0.54 + 0.55 + 0.61 + 0.6}{4}$$

$$y_6 \geq \frac{0.83 + 0.75 + 0.5 + 0.66}{4}$$

$$y_7 \geq \frac{0.68 + 0.6 + 0.57 + 0.6}{4}$$

$$y_8 \geq \frac{0.75 + 0.72 + 0.65 + 0.69}{4}$$

$$y_9 \geq \frac{0.79 + 0.62 + 0.87 + 0.75}{4}$$

$0.7 \le x_1 \le 1$

$0 \le x_2 \le 1$

$0 \le x_3 \le 0.85$

$0 \le x_4 \le 0.8$

$0 \le x_5 \le 1$

$0.65 \le x_6 \le 1$

$0 \le x_7 \le 1$

$0 \le x_8 \le 1$

$0.7 \le x_9 \le 1$

4.2.7 Solving the Model by GAMS

The model is formulated as a mixed-integer non-linear programming model. A powerful modeling tool named GAMS is selected to solve the proposed optimization model. The detailed GAMS program of the case study is shown in Appendix III. The GAMS solver of MINLP (mixed integer non-linear programming) is selected to solve the optimization problem.

4.2.8 Results and Discussions

The results of the QFD optimization model from GAMS are summarized in Tables 4.6 and 4.7. Table 4.6 presents the results of EC fulfillment and corresponding resource allocation. Regarding EC fulfillment, results illustrate not only the level of fulfillment for each EC, but also the selected specific EC value corresponding to its fulfillment level, which provides more practical and useful information for product design. Resource allocation results have specified the amount of resources to be allocated to each EC to achieve the optimal level of fulfillment.

Table 4.7 shows the results of CR fulfillment and customer satisfaction. It can be seen that all the CRs have achieved approximate 0.9 fulfillment levels with limited cost budget of 120 (hundred dollars). As regard to customer satisfaction results, s_i is the actual customer satisfaction achieved by each CR, while CS_i is the full customer satisfaction rate achieved when the fulfillment level of a CR is equal to 1. Dividing s_i by CS_i can obtain the customer satisfaction level for each CR. Normalizing s_i and CS_i with the importance weightings w_i obtain the overall actual satisfaction and overall full satisfaction for the product, respectively. In this case study, the product achieves an overall actual satisfaction rate of 0.5293 out of 0.6512 (overall full satisfaction rate), that is, an overall customer satisfaction level of 81.28%.

ECs	Selected EC options (x_{jk})	EC fulfillment level (x_j)	EC technical value (X_j^*)	Resource allocation (in hundred dollars)
1. CPU	x_{13}	0.800	2.2GHz	15.6
2. RAM	x_{24}	1.000	2 GB	17.5
3. Hard disk	x_{34}	0.850	250G	11.09
4. Graphic card	x_{43}	0.800	256MB	12.8
5. Wireless network card	x_{52}	0.900	Advanced I	11.7
6. LCD display	x_{64}	0.800	15.1"	12.8
7. Optical drive	x_{72}	1.000	8X DVD*+/-RW Drive	15
8. Battery	-	1.000	4 hrs	12
9. Weight	-	0.973	1.578Kg	10.703

Table 4.7 Results of EC fulfillment and resource allocation

CRs	Importance weightings (w_i)	CR fulfillment Level (y_i)	Actual satisfaction (s_i)	Full satisfaction (CS_i)	Customer satisfaction level
Appearance					
1. Stylish design	0.0949	0.922	0.638	0.7661	83.26%
2. Light and mobile	0.1094	0.917	0.597	0.7258	82.29%
Performance					
3. High computing speed	0.1207	0.903	0.583	0.7213	80.71%
4. Powerful graphics solution	0.1139	0.897	0.624	0.8065	77.39%
5. Solid audio capability	0.1178	0.908	0.665	0.8211	81.00%
6. Large storage	0.1142	0.916	0.302	0.3577	84.47%
Function					
7. Multimedia function	0.1194	0.903	0.589	0.7213	81.56%
8. Expandable device	0.1010	0.929	0.567	0.6694	84.72%
9. Wireless LAN	0.1088	0.899	0.200	0.2661	75.07%
Total			**0.5294**	**0.6512**	**81.28%**

Table 4.8 Results of CR fulfillment

It is noted that full satisfaction in this context is not equal to 100%. This is because that full satisfaction in the proposed optimization model is defined as the CS value from Kano's model which is quite different from the traditional approach. The CS value in the proposed model is calculated as CS = (A+O)/(A+O+M+I) and it is normally not equal to 1 for an ordinary CR. To make CS values equal to 1 for attractive and one-dimensional attributes, it should be the case that all the responses vote that CR as attractive or one-dimensional attributes and no response vote for must-be or indifferent requirement. That is, the values of "M" and "I" are both equal to 0 in the above equation. However, this is not common in practice. Moreover, an ordinary product must have certain must-be requirements, that is, some fundamental customer needs that must be fulfilled. There is no chance for the CS value of a must-be requirement to be 0, since the "M" value in the above equation is definitely not equal to 0. The fulfillment of these must-be requirements incurs little customer satisfaction. Due to the aforementioned reasons, full satisfaction for individual CRs cannot reach 100%, which will in turn make the full satisfaction rate for the whole product below 100%.

Following the above analysis of customer satisfaction, two parameters have been found to have the most impact on the customer satisfaction that can be achieved in the proposed QFD optimization model. The first one is the upper technical limits on the level of fulfillment of ECs (ECH_j). Its impact on customer satisfaction is quite straightforward, since some technical restrictions might limit the amount of fulfillment that is possible for a given EC, which will subsequently limit the degree of customer satisfaction with a corresponding CR that can be achieved in the proposed model. Apart from technical constraints, total budget also has great impact on customer satisfaction level as illustrated in Figure 4.6. The figure shows that the achievements of customer satisfaction vary greatly when the budget increases. It should be noted that Figure 4.6 has plotted the relationship between budget allocation and customer satisfaction level with no technical limits on any EC. Under this circumstance, the product can achieve 100% satisfaction level with budget of approximately 135 (hundred dollars).

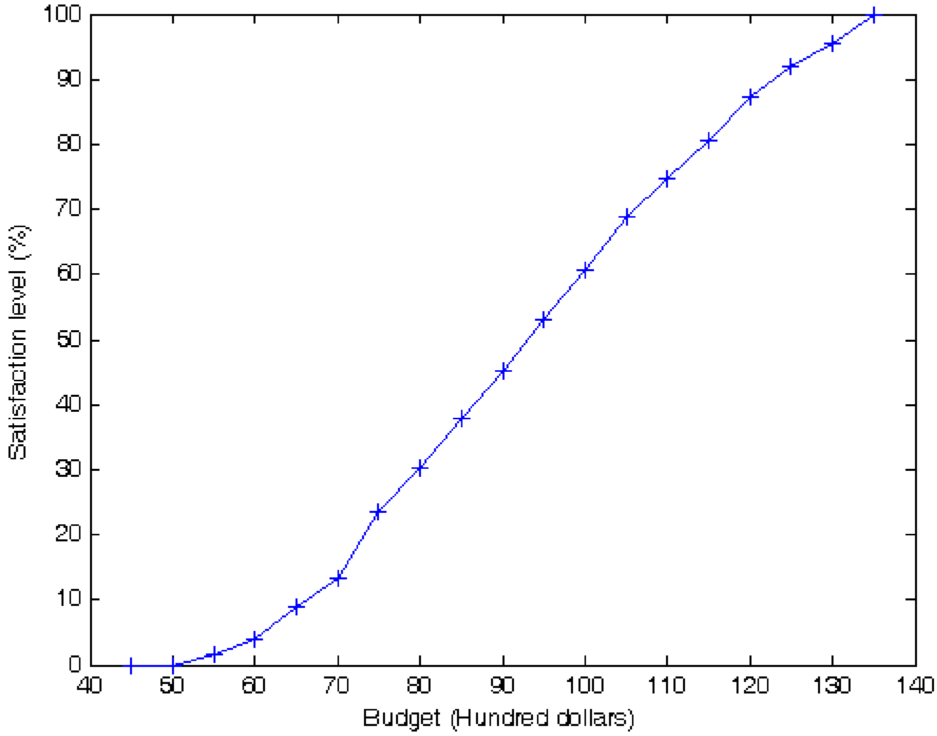

Figure 4.6 Relationship between budget allocation and customer satisfaction level

The results and discussions of the case study demonstrate that the proposed model has two major improvements. First, the way to define customer satisfaction from Kano's model in the proposed model is more objective and practical than the traditional approach. This is because full fulfillment of a certain CR cannot guarantee customers' full satisfaction with that CR. Customers may simply just not need that feature of a product. Kano's model is one solution to address this problem. It classifies CRs on how they are able to impact customer satisfaction. Integrating Kano's model into product design can help companies recognize important CRs that have great impact on customer satisfaction, and avoid the mistake of putting excessive efforts on those CRs customers care little. Kano's model also improves the way to assessing the performance of a product. Mapping the fulfillment level of CRs into customer satisfaction level according to their Kano classification can provide a more objective evaluation of the product than the linear addictive value function used in the traditional approach. Therefore, Kano's model is adopted and integrated into the QFD optimization model to make a more objective projection of customer satisfaction, which will in turn help companies select and deploy ECs in product design to achieve higher customer satisfaction.

In addition to recognizing the different features of CRs in achieving customer satisfaction, it is also of vital importance to note different features of ECs. The proposed model has considered two types of ECs, discrete and continuous. They have been treated differently in the proposed model to determine their optimal level of fulfillment and their specific technical values. This method of determining EC optimal values is quite useful and practical. This is because in practice with various types of products ECs have different characteristics and measurement. It is not appropriate to regard all of them as continuous variables.

4.3 SUMMARY

In this chapter, a case study of notebook computer design is presented to verify and demonstrate the application of the proposed integration approach of Kano's model with QFD optimization. The case study has been conducted by six steps including Kano customer survey, Kano survey analysis, Kano quantitative analysis, construction of the HOQ, normalization of EC values, and integration of Kano's model into QFD optimization.

In Step 1, a typical Kano questionnaire was designed and developed to collect customer needs of a notebook computer. The questionnaire was then distributed to target customers of the case study, that is, undergraduate students from different years of study and various disciplines. Following this, the questionnaire was collected back and analyzed by the traditional Kano's model in Step 2 to determine the Kano category as well as CS and DS values for each CR.

In Step 3, the proposed Kano quantitative analysis was applied to extract quantitative information about customer needs of a notebook computer. The analysis was based on the qualitative results from Kano's model in Step 2 and it finally identified the S-CR relationship function for each CR.

In Step 4, the HOQ of a notebook computer was built to collect all the information for the optimization model including CRs, ECs, normalized relationships between CRs and ECs, benchmarking information, cost index and technical constraints of ECs. After building the HOQ, EC normalization information was collected in Step 5 for the proper transfer of specific EC technical values into level of EC fulfillment in the optimization model. In the final step, an integrative QFD optimization model was formulated to optimize the design of a notebook computer.

By integrating all the information including qualitative and quantitative results from Kano's model, the HOQ and EC normalization information, the QFD optimization model was formulated as a mixed integer nonlinear programming model and solved by the modeling tool GAMS.

The results demonstrate the optimal notebook computer design in terms of EC fulfillment levels and specific EC configurations, achieving approximately 80% overall customer satisfaction level under budget and technical constraints. The case study demonstrates that the proposed approach has improved the traditional QFD analysis in several aspects including capturing and understanding customer needs more accurately, making a more objective projection of customer satisfaction as well as determining EC values in a more practical manner.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 ACHIEVEMENTS

In today's highly competitive market, customer demand is a critical factor in the product design process that faces companies across industrial sectors. Capturing, analyzing and responding to customer demand efficiently and accurately become the essential prerequisites to provide a high quality product and ultimately gaining customer satisfaction. Consistent with this thought, companies nowadays have devoted their efforts to offer customer-defined products to differentiate from their competitors. They have adopted a number of methods and tools to capture and analyze customer needs and hopefully incorporate these requirements into product design to meet customer needs and to achieve higher customer satisfaction.

Quality Function Deployment (QFD) and Kano's model are two methodologies that are widely used by many companies to address the issue of customer focus in product design. QFD, which originated in Japan in 1960s, is a systematic and structured approach to translating CRs into a set of ECs by building a functional matrix called House of Quality. Kano's model, however, concentrates on the analysis of the nature of customer needs. It provides an effective method to understand customer needs by visualizing the diverse relationships between CR fulfillment and customer satisfaction. The inherent nature of Kano's model and QFD has bounded them together in customer-focused product design. The integration of these two methodologies can allow companies to systematically analyze to what extent ECs can be optimized to fulfill customer needs, and in turn will influence customer satisfaction, so that the product can be designed to maximize customer satisfaction under various constraints. However, the literature on integration of Kano's model into QFD reveals that there exist the following three common difficulties in this issue.

- Limited quantitative analysis is involved in analyzing relationships between customer needs and customer satisfaction in Kano's model
- There is limited research on developing a uniform and robust approach to quantitatively integrating Kano's model into QFD.
- Traditional QFD optimization model lacks a uniform and meaningful approach to defining and determining target values for ECs effectively.

In order to solve the aforementioned problems, this research project develops a novel approach to integrating Kano's model into QFD to optimize customer-oriented product design. The integrative approach starts with applying traditional Kano's model to collect and analyze primary customer data in Stage 1. Following that it quantifies Kano's model by identifying relationship functions between customer needs and customer satisfaction. Finally both qualitative and quantitative results from Kano's model in Stages 1 and 2 are integrated into QFD to formulate a mixed integer nonlinear programming model to optimize product design with the objective of maximizing customer satisfaction under cost and technical constraints. A case study concerning the notebook computer design is conducted to illustrate the application of the proposed approach.

5.2 CONTRIBUTIONS

The proposed integrative approach has greatly improved the traditional QFD analysis and has made three major contributions in achieving customer-oriented product design as follows.

Quantification of Kano's model

The quantitative analysis of Kano's model in Stage 2 of the proposed integrative approach goes beyond the traditional qualitative analysis in Kano's model by identifying the relationship functions between CR fulfillment and customer satisfaction for three main categories of CRs. The quantitative analysis of Kano's model helps to understand customer needs in a more accurate way. More importantly, it provides a way for Kano's model to integrate with other mathematical models or tools for optimizing customer-focused product design.

Integration of Kano's model into QFD

The proposed integrative approach involves two aspects of contributions in integration of Kano's model into QFD. On the one hand, traditional Kano's model is employed as the first stage of the integrative approach, which improves the traditional QFD analysis in accurately capturing customer needs from target customers. Traditional Kano's model clearly defines the Kano survey method and the standard classification method by which the survey data can be analyzed to generate a list of important CRs for building the HOQ in QFD. By adopting traditional Kano's model as a starting point, preliminary data for subsequent analysis can be collected accurately and effectively.

One the other hand, the quantitative analysis of Kano's model is integrated into QFD in Stage 3 to establish the objective function of the optimization model, which is more objective than the linear additive value function used in the traditional approach. In doing so, the overall performance of a product can be assessed in a fair manner with consideration of the nuances of different customer needs. Moreover, by differentiating CRs according to their impact on customer satisfaction, the QFD optimization model can help companies recognize important CRs that have great impact on customer satisfaction, and avoid the mistake of putting excessive effort on those CRs which customers care little.

QFD optimization model

The last contribution lies in the issue of target value setting for ECs in the QFD optimization model. The proposed approach has defined a special normalization method to define and determine EC target values for product design and manufacturing operations in a more practical and appropriate way. The normalization method has taken account of both discrete and continuous ECs by transferring their specific technical values into levels of fulfillment and they have been treated differently with appropriate measurement scales to determine their optimal values in the QFD optimization model.

5.3 FUTURE WORK

Since its introduction in 1960s, the research on QFD and its industrial applications have been widely spread all over the world. QFD is seen as an important tool to improve quality, to reduce development and other pre-production costs, to increase organization capabilities and all in all to make industry more competitive. Apart from such business goals, QFD has been widely accepted as a means for the development of products that better fulfill users' needs.

The conventional approach of QFD is well organized in the HOQ as presented in Chapter 2. A number of researchers attempt to further improve in the HOQ analysis by studying some methodological issues including determination of the importance of CRs, assignment of relationships between CRs and ECs, consideration of cost trade-offs and other resource constraints into the optimization model as well as the incorporation of other theories into QFD such as Analytic Hierarchy Process (AHP) and Fuzzy theory. However, there still exist several issues to be investigated for further improvement of the proposed approach, or the QFD analysis as a whole.

Estimation of S-CR relationship functions

In the proposed quantification analysis of Kano's model, S-CR functions have been identified for three main types of CRs, namely attractive, one-dimensional and must-be attributes. The S-CR relationship function for one-dimensional attributes can be accurately identified, since its relationship curve is simply a straight line. However, the S-CR relationship functions for attractive and must-be attributes are based on the assumption that their curves follows the shape of an exponential function. Future work should focus on improving this assumption by deriving more solid data in determining the shape of relationship curves of attractive and must-be attributes objectively.

Incorporation of correlations analysis into the QFD optimization model

The roof of the HOQ specifies the correlations among different ECs. These correlations, positive or negative, have great impact on the analysis of other parts in the HOQ. Although the conventional QFD approach obtains information about correlations among ECs in the triangular-shaped correlation matrix at the top of HOQ, the correlation analysis were often ignored in the QFD analysis due to its complexity. Therefore, it is critical to incorporate the correlations among ECs to reflect the positive or negative impact among them in determining EC optimal values.

The idea of correlations can be further extended to CRs, since it is possible that CRs also have the negative or positive impact to each other. These correlations may affect the decisions in determining the importance of CRs, the relationships between CRs and ECs and target values for ECs. Therefore, future work should focus on developing uniform approaches in measuring the correlations among CRs and ECs as well as incorporating them into the QFD optimization model.

Consideration of negative relationships between CRs and ECs

The conventional QFD approach presupposes that the relationships between CRs and ECs are always non-negative. This assumption can cause some problems, as can be illustrated with the car example presented by Poel [Poe07]. One of the customer demands for cars is “fuel consumption”. This can, for example, be achieved through the EC “weight of the car”, i.e. lighter cars have lower fuel consumption *ceteris paribus*. However, lighter cars get a higher relative acceleration in collisions with heavier cars and, therefore, are more dangerous to the driver and passengers. So, while the engineering characteristic “weight of the car” correlates positively with the customer demand “safety for the driver and for the passengers”, it correlated negatively with the customer demand “fuel consumption”. Therefore, the consideration of these negative relationships is quite necessary and important to accurately reflect the relationships between CRs and ECs. More research can be directed towards improving the measurement scale, the assignment of relationships between ECs and CRs as well as the normalization of the relationships matrix.

In summary, this research project has developed a novel approach for QFD optimization with Kano’s model. The proposed approach has made major contributions in optimizing product design with primary focus in customer needs by integrating Kano’s model into QFD optimization model. It should be noted that more research could be directed to the correlation analysis in the HOQ and further improvement in the quantitative analysis of Kano’s model. And finally, more applications on the product design problems would further test the usefulness of the proposed approach.

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APPENDIX I

KANO CUSTOMER SURVEY

CUSTOMER SURVEY ABOUT NOTEBOOK COMPUTER DESIGN

We would like you to take a few minutes to complete this customer survey that examines your views of the notebook computer design from four aspects: appearance, performance, function and services.

This survey includes 3 sections. Section 2 and 3 examines the notebook computer design from two different perspectives: ***functional*** *and* ***dysfunctional*** *forms, which are independent from each other.*
The ***functional form*** *asks how you feel if a feature were included in the notebook computer system.*
The ***dysfunctional form*** *asks how you would feel if the same feature were omitted from the notebook computer system.*

When you finish the questionnaire, please send it to **wtcherry913@**
Thanks very much for your participation!

SECTION 1: NOTEBOOK COMPUTER USAGE

Please describe your prime usage for a notebook computer (please check one only)
O Basic performance
O Advanced computing
O Mobile work with lightweight
O Multimedia entertainment
O Others

SECTION 2: FUNCTIONAL FORM

Consider each attribute one at a time and how you would feel if it was included. Please check only one out of the following five choices for each row.

1 = I like this feature included.
2 = This feature must be included.
3 = I am neutral about this feature.
4 = I can live with including this feature.
5 = I dislike including this feature.

	1	2	3	4	5
APPEARANCE					
Light and mobile	O	O	O	O	O
Stylish design	O	O	O	O	O
Large screen size	O	O	O	O	O
PERFORMANCE					
High computing speed	O	O	O	O	O
Solid audio capabilities	O	O	O	O	O
Powerful graphics solution	O	O	O	O	O
Large storage	O	O	O	O	O
High network performance	O	O	O	O	O
FUNCTION					
Multimedia function	O	O	O	O	O
Expandable device	O	O	O	O	O
Wireless LAN	O	O	O	O	O
Remote control	O	O	O	O	O
SERVICES					
On-site installation	O	O	O	O	O
Software support	O	O	O	O	O
24x7 Phone technical support	O	O	O	O	O
3-year replacement and repair service	O	O	O	O	O

SECTION 3: DYSFUNCTIONAL FORM

The same attributes mentioned in Section 2 could be omitted from the notebook computer system. Consider each attribute one at a time and how you would feel if it was not included (omitted). Please check only one out of the following five choices for each row.

1 = I like this feature omitted.
2 = This feature must be omitted.
3 = I am neutral about this feature.
4 = I can live with omitting this feature.
5 = I dislike omitting this feature.

	1	**2**	**3**	**4**	**5**
APPEARANCE					
Light and mobile	O	O	O	O	O
Stylish design	O	O	O	O	O
Large screen size	O	O	O	O	O
PERFORMANCE					
High computing speed	O	O	O	O	O
Solid audio capabilities	O	O	O	O	O
Powerful graphics solution	O	O	O	O	O
Large storage	O	O	O	O	O
High network performance	O	O	O	O	O
FUNCTION					
Multimedia function	O	O	O	O	O
Expandable device	O	O	O	O	O
Wireless LAN	O	O	O	O	O
Remote control	O	O	O	O	O
SERVICES					
On-site installation	O	O	O	O	O
Software support	O	O	O	O	O
24x7 Phone technical support	O	O	O	O	O
3-year replacement and repair service	O	O	O	O	O

APPENDIX II

RESULTS OF THE SELF-STATED IMPORTANCE QUESTIONNAIRE

CRs / Importance Ratings	1. Stylish design	2. Light and mobile	3. High computing speed	4. Powerful graphics solution	5. Solid audio capability	6. Large storage	7. Multimedia function	8. Expandable device	9. Wireless LAN
1	7	5	5	6	8	4	7	4	5
2	6	8	8	5	5	7	6	6	6
3	2	4	8	6	6	5	8	5	5
4	4	8	6	8	7	4	7	5	6
5	5	5	7	4	5	7	8	5	4
6	6	5	6	5	5	4	7	5	7
7	3	6	5	6	5	3	7	4	7
8	8	5	6	4	6	5	6	5	6
9	5	8	5	6	7	7	5	7	5
10	4	7	6	5	5	6	8	6	6
11	6	5	7	5	5	6	7	4	8
12	5	3	7	6	8	4	5	5	8
13	6	8	5	5	7	5	8	5	4
14	7	4	7	7	7	8	6	6	7
15	4	5	6	6	6	7	7	5	6
16	3	6	6	5	7	5	7	7	5

17	5	6	5	5	6	6	5	5	7
18	7	7	5	7	6	5	6	5	7
19	5	6	6	5	7	6	5	6	5
20	6	7	5	8	5	7	9	5	7
21	4	6	6	8	7	6	7	6	6
22	3	6	7	5	6	6	7	5	5
23	3	4	7	5	5	4	6	6	4
24	2	5	9	6	6	7	6	7	5
25	5	6	6	6	8	6	5	4	3
26	6	3	5	5	5	5	6	7	6
27	7	6	9	6	6	5	7	6	7
28	3	5	5	7	6	7	6	4	5
29	7	4	5	6	7	6	8	5	7
30	3	6	7	5	5	7	5	5	5
31	5	5	6	6	5	6	7	4	6
32	3	5	6	5	6	5	6	7	7
33	3	7	7	8	6	7	5	4	4
34	5	5	5	9	7	6	6	3	9
35	6	4	4	6	5	5	8	5	6
36	2	7	8	7	6	5	8	6	4
37	4	6	7	5	7	6	7	6	8
38	8	5	6	7	7	8	4	7	4
39	7	6	5	5	5	4	6	5	5
40	3	7	6	6	8	5	5	5	8
41	6	7	8	7	4	7	5	4	4
42	5	6	5	6	6	8	6	6	6
43	4	6	6	5	8	7	5	5	7
44	4	5	7	5	5	5	6	6	8
45	7	9	5	5	7	6	6	6	6
46	4	5	5	5	6	6	7	4	5

47	3	4	7	8	7	7	5	3	6
48	6	6	7	5	8	6	5	3	5
49	3	8	6	3	5	5	5	6	3
50	6	7	8	5	6	4	8	5	6
51	3	5	5	6	6	7	7	6	4
52	5	6	5	7	6	6	9	7	4
53	4	7	6	6	5	4	5	3	6
54	7	4	7	6	7	6	5	6	7
55	5	6	4	6	5	5	6	6	5
56	4	7	6	7	7	4	6	5	4
57	5	5	6	5	8	7	5	4	7
58	6	7	7	6	6	5	8	6	4
59	4	6	6	7	7	8	6	7	4
60	4	5	8	7	5	6	8	6	5
61	5	8	5	6	6	8	5	4	6
62	5	4	7	7	7	6	5	4	6
63	3	5	6	5	7	7	6	5	4
64	5	6	5	7	6	6	5	5	5
65	3	6	8	6	5	5	8	6	5
66	5	5	7	5	8	6	6	5	7
67	6	8	5	8	7	5	4	4	6
68	7	7	6	6	7	8	7	5	5
69	4	7	6	4	6	9	8	6	4
70	6	6	5	6	6	6	7	7	7
71	6	5	8	7	6	7	5	5	6
72	7	4	6	5	8	7	6	6	5
73	3	6	6	8	7	6	6	6	3
74	6	7	5	5	6	6	5	8	7
75	4	5	8	6	5	3	6	5	5
76	5	5	7	6	6	5	7	7	5

77	8	8	7	5	5	7	6	6	6
78	5	6	6	8	6	7	5	6	4
79	5	4	5	7	6	5	4	8	5
80	5	4	4	7	7	6	8	4	5
81	6	8	6	6	9	5	5	3	7
82	2	7	7	5	7	5	7	6	4
83	4	6	5	6	7	8	5	3	6
84	4	6	5	5	6	5	6	4	5
85	5	5	8	8	5	6	4	5	5
86	4	4	6	4	5	7	6	5	6
87	7	6	4	7	7	5	6	3	7
88	7	7	6	8	6	8	5	6	6
89	6	4	8	5	5	6	7	2	7
90	4	6	9	6	6	4	6	3	6
91	5	6	7	7	5	6	7	5	6
92	7	5	7	5	7	7	6	5	3
93	6	6	8	7	5	6	8	6	5
94	5	4	6	6	6	5	7	7	4
95	6	5	5	5	5	9	6	5	5
96	4	6	7	7	6	7	7	8	7
97	5	7	6	6	5	7	4	3	8
98	4	6	4	6	4	8	5	5	7
99	7	5	8	4	5	6	6	6	5
100	6	4	5	5	6	5	7	5	7
101	5	6	6	6	7	7	8	7	6
102	7	5	6	5	6	6	5	7	5
103	4	7	8	5	6	4	6	5	6
104	4	6	6	8	5	8	5	6	5
105	5	5	7	7	4	7	7	3	6
106	6	4	6	7	5	6	6	4	7

107	5	7	5	6	6	5	5	6	5
108	6	6	9	5	5	8	7	5	6
109	4	5	6	6	7	6	7	4	6
110	4	7	8	6	8	5	6	6	8
111	5	3	7	6	5	7	5	5	7
112	7	4	6	5	5	7	8	5	7
113	4	5	7	5	9	8	7	8	5
114	6	6	7	8	7	5	8	5	6
115	2	5	6	6	6	5	6	6	7
116	3	6	6	6	6	4	7	4	6
117	5	4	8	7	8	6	7	5	4
118	7	6	7	4	6	7	6	4	5
119	5	5	7	5	7	6	7	6	8
120	6	8	6	5	7	5	5	5	4
121	3	4	8	6	6	6	6	6	7
122	7	7	5	6	5	5	5	7	6
123	4	8	6	8	6	7	6	6	5
124	5	5	7	4	7	4	5	5	4
125	6	4	8	5	6	6	8	6	6
Total	620	714	788	743	769	746	779	659	710
Relative Importance (%)	**9.49**	**10.94**	**12.07**	**11.39**	**11.78**	**11.42**	**11.94**	**10.10**	**10.88**

APPENDIX III

GAMS PROGRAM

```
$EOLCOM #
$INLINECOM { }

SETS
   I1  A CUSTOMER REQUIREMENTS      /CR1, CR4, CR5, CR8/
   I2  O CUSTOMER REQUIREMENTS      /CR2, CR3, CR7/
   I3  M CUSTOMER REQUIREMENTS      /CR6, CR9/
   J   ENGINEERING CHARACTERISTICS   /EC1 * EC9/
   P1  EC CHOICE 1              /EC11 * EC14/
   P2  EC CHOICE 2              /EC21 * EC24/
   P3  EC CHOICE 3              /EC31 * EC35/
   P4  EC CHOICE 4              /EC41 * EC44/
   P5  EC CHOICE 5              /EC51 * EC53/
   P6  EC CHOICE 6              /EC61 * EC65/
   P7  EC CHOICE 7              /EC71 * EC72/
   T  COMPETITORS                 /COMP1 * COMP4/;

PARAMETERS
W1(I1) IMPORTANCE WEIGHTINGS OF CR I = 1 4 5 8
/CR1  0.0949
 CR4  0.1139
 CR5  0.1178
 CR8  0.1010/
W2(I2) IMPORTANCE WEIGHTINGS OF CR I = 2 3 7
/CR2  0.1094
 CR3  0.1207
 CR7  0.1194/
W3(I3) IMPORTANCE WEIGHTINGS OF CR I = 6 9
/CR6  0.1142
 CR9  0.1088/

A1(I1) A IN THE S-CR FUNCTIONS I = 1 4 5 8
/CR1 0.6289
 CR4 0.6852
 CR5 0.6529
 CR8 0.5491/
A2(I2) A IN THE S-CR FUNCTIONS I = 2 3 7
/CR2 1.5484
 CR3 1.4344
```

```
 CR7 1.3852/
A3(I3) A IN THE S-CR FUNCTIONS I = 6 9
/CR6 1.7235
 CR9 1.6968/

B1(I1) B IN THE S-CR FUNCTIONS I = 1 4 5 8
/CR1 -0.9434
 CR4 -1.0562
 CR5 -0.9538
 CR8 -0.8233/
B2(I2) B IN THE S-CR FUNCTIONS I = 2 3 7
/CR2 -0.8226
 CR3 -0.7131
 CR7 -0.6639/
B3(I3) B IN THE S-CR FUNCTIONS I = 6 9
/CR6 0.9917
 CR9 0.8903/

C(J) COST OF UNIT IMPROVEMENT FOR EC J
/ EC1   19.5
  EC2   17.5
  EC3   14
  EC4   16
  EC5   13
  EC6   16
  EC7   15
  EC8   12
  EC9   11/

D1(P1)
/ EC11  0.4
  EC12  0.6
  EC13  0.8
  EC14   1 /
D2(P2)
/ EC21  0.25
  EC22  0.5
  EC23  0.75
  EC24  1/
D3(P3)
/ EC31  0.2
  EC32  0.4
  EC33  0.6
  EC34  0.85
  EC35    1/
D4(P4)
/ EC41  0.4
```

```
  EC42  0.6
  EC43  0.8
  EC44  1/
D5(P5)
/ EC51  0.6
  EC52  0.9
  EC53    1/
D6(P6)
/ EC61  0.2
  EC62  0.4
  EC63  0.6
  EC64  0.8
  EC65    1/
D7(P7)
/ EC71  0.7
  EC72    1/;

TABLE R1(I1,J) RELATIONSHIPS BETWEEN CR I AND EC J
      EC1     EC2     EC3     EC4     EC5     EC6     EC7     EC8     EC9
CR1 0.0603    0.0832    0.0747    0.0606    0.0529    0.1562    0.1366    0.1700
0.2054
CR4 0.1433    0.1459    0.1234    0.1424    0.1079    0.0710    0.0578    0.1266
0.0818
CR5 0.1493    0.1672    0.1494    0.1294    0.0851    0.0150    0.0956    0.1268
0.0821
CR8 0.0747    0.1037    0.0881    0.0772    0.0662    0.0789    0.1518    0.1757
0.1835

TABLE R2(I2,J)
      EC1     EC2     EC3     EC4     EC5     EC6     EC7     EC8     EC9
CR2 0.0871    0.1031    0.0873    0.0866    0.0701    0.1182    0.1219    0.1573
0.1685
CR3 0.1558    0.1648    0.1494    0.1411    0.0999    0.0153    0.0694    0.1322
0.0722
CR7 0.1324    0.1442    0.1197    0.1322    0.0988    0.0602    0.0858    0.1309
0.0957

TABLE R3(I3,J)
      EC1     EC2     EC3     EC4     EC5     EC6     EC7     EC8     EC9
CR6 0.1296    0.1775    0.1761    0.0988    0.0588    0.0180    0.1137    0.1285
0.0989
CR9 0.1087    0.1513    0.0498    0.2189    0.2597    0.0067    0.0375    0.1348
0.0326

TABLE CMP1(I1,T) THE PERFORMANCE OF CR I BY COMPETITOR T
     COMP1   COMP2   COMP3   COMP4
CR1   0.85    0.74    0.70    0.76
```

```
CR4   0.90   0.84   0.75   0.71
CR5   0.54   0.55   0.61   0.60
CR8   0.75   0.72   0.65   0.69

TABLE CMP2(I2,T)
     COMP1   COMP2   COMP3   COMP4
CR2   0.60   0.71   0.45   0.60
CR3   0.72   0.55   0.40   0.47
CR7   0.68   0.60   0.57   0.60

TABLE CMP3(I3,T)
     COMP1   COMP2   COMP3   COMP4
CR6   0.83   0.75   0.50   0.66
CR9   0.79   0.62   0.87   0.75;

SCALAR TC TOTAL BUDGET FOR PRODUCT DEVELOPMENT /120/;

POSITIVE VARIABLES
   X(J)  NORMALIZED VALUE OF EC J
   Y1(I1)  DEGREE OF FULFILLMENT OF CR I
   Y2(I2)
   Y3(I3)
   S1(I1)  INDIVIDUAL CUSTOMER SATISFACTION
   S2(I2)
   S3(I3) ;
BINARY VARIABLES
   X1(P1)
   X2(P2)
   X3(P3)
   X4(P4)
   X5(P5)
   X6(P6)
   X7(P7);
VARIABLES
   TS    OVERALL CUSTOMER SATISFACTION;


EQUATIONS
   OBJ   OBJECTIVE FUNCTION

   CREC1(I1)  CR-EC FUNCTION
   CREC2(I2)
   CREC3(I3)
   CRS1(I1)  S-CR FUNCTION TYPE 1
   CRS2(I2)  S-CR FUNCTION TYPE 2
   CRS3(I3)  S-CR FUNCTION TYPE 3
   COST  COST FUNCTION
```

```
   BENCH1(I1) BENCHMARKING FUNCTION
   BENCH2(I2)
   BENCH3(I3)
   SP1
   SP2
   SP3
   SP4
   SP5
   SP6
   SP7
   AP1
   AP2
   AP3
   AP4
   AP5
   AP6
   AP7;

SP1..      X('EC1')   =E= SUM(P1,D1(P1)*X1(P1));
SP2..      X('EC2')   =E= SUM(P2,D2(P2)*X2(P2));
SP3..      X('EC3')   =E= SUM(P3,D3(P3)*X3(P3));
SP4..      X('EC4')   =E= SUM(P4,D4(P4)*X4(P4));
SP5..      X('EC5')   =E= SUM(P5,D5(P5)*X5(P5));
SP6..      X('EC6')   =E= SUM(P6,D6(P6)*X6(P6));
SP7..      X('EC7')   =E= SUM(P7,D7(P7)*X7(P7));
AP1..       SUM(P1,X1(P1))=E= 1;
AP2..       SUM(P2,X2(P2))=E= 1;
AP3..       SUM(P3,X3(P3))=E= 1;
AP4..       SUM(P4,X4(P4))=E= 1;
AP5..       SUM(P5,X5(P5))=E= 1;
AP6..       SUM(P6,X6(P6))=E= 1;
AP7..       SUM(P7,X7(P7))=E= 1;

CREC1(I1)..  Y1(I1) =E= SUM(J, R1(I1,J)*X(J));
CREC2(I2)..  Y2(I2) =E= SUM(J, R2(I2,J)*X(J));
CREC3(I3)..  Y3(I3) =E= SUM(J, R3(I3,J)*X(J));
CRS1(I1)..  S1(I1) =E= A1(I1)*EXP(Y1(I1))+B1(I1);
CRS2(I2)..  S2(I2) =E= A2(I2)*Y2(I2)+B2(I2);
CRS3(I3)..  S3(I3) =E= -A3(I3)*EXP(-Y3(I3))+B3(I3);

OBJ..   TS =E= SUM(I1, W1(I1)*S1(I1))+SUM(I2, W2(I2)*S2(I2))+SUM(I3,
W3(I3)*S3(I3));

COST..   SUM(J, X(J)*C(J)) =L= TC;
BENCH1(I1)..  Y1(I1) =G= SUM(T, CMP1(I1,T))/4;
BENCH2(I2)..  Y2(I2) =G= SUM(T, CMP2(I2,T))/4;
BENCH3(I3)..  Y3(I3) =G= SUM(T, CMP3(I3,T))/4;
```

```
X.UP(J) = 1;
X.LO(J)  =0;


X.LO('EC6')  =0.65;
X.LO('EC1')  =0.7;
X.LO('EC9')  =0.7;
X.UP('EC3')  =0.85;
X.UP('EC4')  =0.85;


MODEL QFD /ALL/ ;

SOLVE QFD USING MINLP MAXIMIZING TS;
```